GLASS

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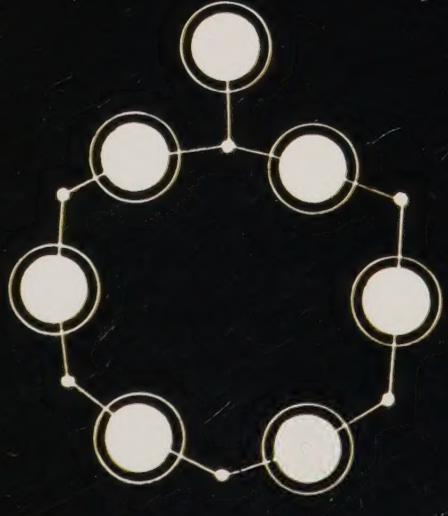
MAKING GLASS



GLASS MANUFACTURERS FEDERATION

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Glass

This book has been written for the use of teachers. It is a summary of the principal glasses in use today, the methods by which they are made into products and, where appropriate, further processed. For those who wish to supplement this information, we recommend the leaflet ABOUT BRITISH GLASS which contains a reading list and advice on the facilities available from the Glass Manufacturers' Federation.

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What is Glass?

What is Glass? Scientists do not yet know precisely but generally it may be said that it is the substance formed by melting mixtures of various inorganic substances and then cooling the melt in a manner which prevents crystallization—that is, the molecules never arrange themselves in a crystalline pattern. Thus many different glasses, with properties differing according to the raw materials used, can be made.

Silica sand (SiO_2) is the main ingredient of most commercially important glasses but very high temperatures are needed to melt silica alone. Fused silica, which is used for several high-temperature applications, vitrifies when melted at about 1,700°C. Glasses melting at a lower temperature can be made by adding *fluxing-agents* to the silica sand: for instance *soda ash* (Na_2CO_3). The addition of 25 per cent of soda ash to silica sand reduces the melting temperature to about 800°C. But the resulting substance is *waterglass* (Na_2SiO_3), which is soluble in water.

However, a *stabilizer* such as *limestone* ($CaCO_3$) can be added and a non-soluble glass obtained. A glass for ordinary bottles and jars can be made basically from 15 parts sand (SiO_2)

5 parts soda ash (Na_2CO_3)

4 parts limestone ($CaCO_3$)

The raw materials having been carefully weighed are mixed and heated to about 1,500°C. and over a period of time they gradually melt and react.

To assist melting, 15 per cent to 30 per cent of *cullet* (scrap glass) is often added to these raw materials. Great care is taken to ensure that this cullet added to the *batch* is of the same composition as that being melted. Any variation could spoil the quality of the glass produced.

Glass-melting Furnaces

Glass-melting furnaces are constructed from special refractory materials which do not affect the glass. There are two main types of glass-melting furnace.

Pot Furnace

The traditional *pot furnace* heats one or more fireclay melting pots. Two early pot furnaces were: the *Theophilus*, a rectangular structure where the pots were set in a platform, and the *Agricola*. The latter was conical in three levels: the lowest held the fire, the middle the pots, while the space at the top was used for *annealing*, or cooling, the formed glass. Each modern pot holds up to 15 cwt of glass, and has to be replaced periodically.

Tank Furnace

The *tank furnace* melts the raw materials for a continuous flow of glass, needed where automatic forming machinery is used. It is more economical in its use of fuel and is used for all large-scale glass production. A tank furnace has a capacity of up to 2,000 tons of glass. It was introduced in the second half of the nineteenth century. The glass-melting tank is in operation day and night for a period of over two years, after which it is rebuilt.

When the glass is fully melted it is ready for making into finished products: this process is known as *forming*.

Glass-forming Processes

Glass-forming processes are all based on the fact that the viscosity of glass changes as its temperature changes. Water, glycerine, treacle, and pitch, for example, are all liquids, but each has a different viscosity. The viscosity of glass increases as the temperature falls.

Blown

Mouth blowing, which until this century was, for nearly 2,000 years, the main glass-forming method, employs this viscous property of glass in the following way.

The glass is gathered by dipping a hollow *blowing-iron* into a pot of molten glass. The *gob*, or *gather*, of glass cools to about 1,000°C. It is then *marvered* (rolled on an iron slab) to form a chilled layer on the outside surface of the hot glass. This layer or skin sustains the internal pressure of the glassmaker's breath as he blows down the iron. Blowing also forms another cooled layer on the inner surface. Distribution of the viscous glass and the relative wall thickness are regulated by blowing, by shaping with tools (often made of a fruitwood which forms a smooth charcoal surface in contact with the hot glass), and by raising or lowering the end of the constantly rotated blowing-iron to allow the more fluid glass between the surfaces to flow back and forth.

Mouth-blown glassware may also be shaped, especially in the early stages of forming an article, by blowing the glass into a mould and this works on the same principle of giving a cooled outer layer.

For the *Semi-Automatic* method the gob of molten glass gathered manually on a rod is dropped into the *parison mould*. An embryo shape is formed which determines the final distribution of glass. This parison is then transferred manually to the *blow mould* and blown out to its final shape by compressed air.

With the completely *Automatic* method the gob of molten glass (extruded through an orifice in the forehearth of the tank furnace) is sheared off to the exact size as it drops into the parison mould. It is automatically transferred into the blow mould and then taken on a conveyor belt to the annealing *lehr*, or oven, for controlled cooling.

Drawn

Molten glass may also be *drawn* off from the furnace.

Sheet glass is drawn upwards continuously from a tank. The ribbon is started on a metal former known as a *bait*. Thickness is determined by the rate of drawing and the width is kept constant by passing the edges of the ribbon through cooled rollers. These chill the

edges of the glass. The chilled edges then act as supports for the less viscous glass suspended in between them.
For *Tube drawing* the size of *mandrel* (a revolving fireclay hollow cylinder), air pressure and rate of drawing influence diameter and wall thickness.
Glass filaments are also drawn. The effect that skilled lampworkers have produced for many years by heating a rod of glass and drawing apart the two ends very quickly is simulated mechanically. In automatic production the glass flows through minute orifices and is either drawn off by a spindle or attenuated by a blast of air or by centrifugal action.

Rolled Molten glass may *flow* from the tank continuously between water-cooled rollers, thickness being determined by the spacing of the rollers. The rollers may be embossed to impart a surface pattern on the glass—*Rolled Figured glass*; or the parallel surfaces may be ground in the same continuous process and then polished to provide clear undistorted vision—*Polished Plate glass.*

Float Process There are two very recently developed methods of forming glass. In one, a continuous ribbon of glass flows from the tank to *float* on the surface of molten tin at a controlled temperature in a controlled atmosphere. This produces a ribbon with remarkably flat and parallel surfaces, giving undistorted vision. This glass needs neither grinding nor polishing.

Extruded In the other, specially refined molten glass is *extruded* from a tank in the form of blanks. These can afterwards be reheated and pressed into any required shape.

Pressed *Pressing* is used for objects with a simple basic shape where the opening is wider than the base; this does not restrict surface decoration which may be complicated. A plunger is used to form the inner surface of the article by pushing the glass against the outer mould. Pressing can be hand-operated or fully automatic.

Cast Molten glass is poured out and allowed to set in a block. After controlled cooling it may be cracked or sawn into small pieces, ground, and polished.

Types of Glasses

Having considered the basic behaviour of any glass and how it may be treated in order to be formed into useful objects, the nature of various specific glasses can be examined. There is a wide range of glass products and each type requires special properties. Ovenware, for example, must resist heat; windscreens must withstand mechanical shock and atmospheric conditions, whilst glasses which act as selective light filters, which have everyday applications in photography, are needed for protection in industry and research. The physical properties of a glass are primarily determined by its chemical composition. There are many thousands of different glasses. They can, however, be considered in three main groups.

Soda-Lime-Silica Glasses

This is the most important group in terms of tonnage melted and variety of use. The combination of silica sand, soda ash, and limestone produces a glass that is easily melted and shaped, and has good chemical durability. The raw materials are indigenous and therefore it is cheap to produce. This group is particularly suited to automatic forming methods. Very small amounts, often less than 1 per cent of the total batch, of alumina, magnesia, boric oxide, and other chemicals are added to act as stabilizers and increase durability in certain instances.

The natural colour of this group of glasses tends to be greenish (cf. Roman glass and old bottles) and is caused by the natural iron content of the sand. This can be corrected by the use of minute quantities of selenium or manganese. If increased amounts of these were used they would colour the glass. For colourless glass the iron content of the sand should be below 0·03 per cent.

Lead Glasses

The glasses of this group, composed basically of silica sand (as iron-free as possible), potash, and lead oxide, have a high refractive index and high electrical resistivity (increased by the potash content). The slow rate of increase in viscosity with decrease in temperature makes lead glass particularly suitable to hand-made production. The amount of lead may vary considerably—even up to 92 per cent lead oxide. It is not a cheap glass to produce for the raw materials are relatively expensive and special care is needed in melting to avoid bubbles and *seed*. Glasses of this type are used for high-quality domestic ware and for special electrical and nuclear engineering purposes.

Borosilicate Glasses

This group of glasses is basically a combination of silica sand and boric oxide, which is here used as a fluxing agent. This permits less alkali to be used and gives the glasses improved chemical stability and electrical properties. They have low thermal expansion giving high resistance to thermal shock. High durability makes them ideal for demanding industrial and domestic use. These glasses were developed in the early part of this century to cope with the problem of cold rain on hot railway signal lights.

There are, of course, infinite variations on these glasses. Other factors, especially economic, being equal, a glass may be made to fit the exact requirements of the user. Glasses for *glass-to-metal seals* are a good example of this. Where lighting engineers want to take advantage of the high electrical and thermal conductivity of certain metals, glasses have to be developed which will retain the seal between the metal and the glass over a range of temperatures from atmospheric to that at which the seal is made.

PRODUCT	SPECIFIC QUALITIES	METHOD OF MANUFACTURE AND PRINCIPAL USES	GROUP AND TYPICAL FORMULA
BOTTLES AND JARS	Economical to produce. Easy to manufacture by mass-production methods. Resistant to mechanical shock: (i) some filling lines fill at the rate of 600 bottles a minute; (ii) capable of being used for fifty trips or more (i.e. milk bottles). Resistant to thermal shock (e.g. sterilization of food). Impervious to odours and flavours. Inert—do not affect the contents in any way (especially food and milk). Resistant to chemical attack. Easily cleansed.	Semi-Automatic Blowing: 1% total production of bottles and jars for small quantities and special colours, e.g. fancy and small bottles for pharmaceutical and cosmetic industries. Automatic Blowing: 99% total production of bottles and jars; clear (flint), green, amber, blue, opal.	*Soda-lime-silica glass* % SiO_2 73·0 Na_2O 15·0 CaO 10·0 Al_2O_3 1·0 SO_3 0·2 F_2 0·1 Fe_2O_3 0·05 In this and subsequent formulae minute quantities of other inorganic chemicals are added for specific purposes.
FLAT GLASS	Economical to produce. Easy to manufacture by mass-production methods. Resistant to mechanical shock: windows and doors have to stand hard usage. Easily toughened. Optically good—today, unlike our ancestors in the Middle Ages, we can see out of our glass windows. Weather resistant.	Sheet Drawing: windows Drawing and Rolling: obscured windows. Polished Plate and Float Glass: windows, doors, mirrors, windscreens.	*Soda-lime-silica glass* % SiO_2 72·5 Na_2O 13·0 CaO 9·3 MgO 3·0 Al_2O_3 1·5 K_2O 0·3 SO_3 0·3 Fe_2O_3 0·1
DOMESTIC GLASSWARE for everyday use in home and catering	Pleasant appearance and clarity. Ability to stand up to constant use including impact and thermal shock. Inert—does not affect contents in any way. Can be automatically mass-produced when quantities warrant.	Mouth Blowing: for versatility of shape; mostly drinking glasses. Automatic Blowing: simple, elegant basic shapes; drinking glasses and tumblers. Hand and Automatic Pressing: for shapes with a wide open top which enables the plunger to be withdrawn; general domestic glassware.	*Soda-lime-silica glass* % SiO_2 70·5 Na_2O 16·5 CaO 5·5 MgO 3·0 Al_2O_3 2·5 K_2O 1·2 Fe_2O_3 0·03 B_2O_3 0·5

PRODUCT	SPECIFIC QUALITIES	METHOD OF MANUFACTURE AND PRINCIPAL USES	GROUP AND TYPICAL FORMULA
DOMESTIC GLASSWARE: tableware (Full Lead Crystal)	Long working range: suited to British *chair* technique of making mouth-blown glass, which involves blowing, tooling, and smoothing. Brilliant finish: looks attractive, full or empty, and is particularly suited to drinking glasses. Comparatively soft: easy to cut and polish or engrave. Cutting is a British technique which developed with British Lead Crystal glass and is particularly suited to its high refractive index.	Mouth Blowing: by a team, or *chair* (from glassmaker's chair), of up to five, each with separate jobs. *Gatherer, Servitor, Footmaker, Maker* or *Gaffer* (the chief man), and the *Boy* (apprentice) who takes finished pieces to the annealing lehr. Teamwork is important for on it depends the rate of production. Moulds may be used. Hand Pressing: for articles with simple basic shape.	*Lead glass* % SiO_2 55·5 PbO 33·0 K_2O 11·0 Fe_2O_3 0·025 See British Standard 3828: 1964
DOMESTIC GLASSWARE: oven-to-table and flame ware	Resistant to thermal shock. Attractive. Easy to clean.	Automatic Pressing: casseroles, basins, cups, etc. Automatic Blowing: coffee pots, tumblers.	*Borosilicate glass* % SiO_2 80·0 B_2O_3 12·2 Na_2O 4·5 Al_2O_3 2·5
OPTICAL GLASS (including ophthalmic glass and colour filters)	Wide range of controlled refractive indices. Wide range of dispersion. Homogeneity and freedom from flaws. Chemical and physical stability. Complete transparency—so that one can see through a thick block.	Extrusion and Pressing: glass blanks are subsequently remelted and pressed to specific shapes and then precision-ground and polished for optical components.	*Glasses of widely ranging compositions* are melted to obtain required properties.
RADIATION SHIELDING	A special form of optical glass which must have the following additional properties: High density to absorb radiation (cf. lead). Complete visibility. Stability against darkening caused by radiation.	Extrusion and Casting: glass blanks are subsequently ground and polished to optical precision.	*Lead glass* Much of the glass is cerium-stabilized. % SiO_2 30·0 PbO 65·0 K_2O 3·0

PRODUCT	SPECIFIC QUALITIES	METHOD OF MANUFACTURE AND PRINCIPAL USES	GROUP AND TYPICAL FORMULA
THERMOMETER TUBING	Thermal stability: in use and during sterilization. Transparency.	Automatic and Hand Drawing: some thermometer tubing especially for clinical use is opal glass backed to give clear readings.	*Soda-lime-silica*, *Borosilicate and Full Lead Crystal* glasses are used for clinical thermometers, and a wide range of compositions for other thermometers according to temperature range.
LABORATORY GLASSWARE	Chemical stability under exacting conditions. Low thermal expansion.	Lampworking: glass tubing is reheated over a gas flame boosted by compressed air or oxygen and is blown and manipulated with tools by skilled lampworkers. Lathes are used to an increasing extent. Mouth and Automatic Blowing: flasks, beakers, and cylinders. Hand and Automatic Pressing: dishes, etc. Grinding: the ends of interlocking pieces are ground on a flat table or on a lathe to B.S. specifications to ensure a perfect air- and water-tight seal. Sintering: filters are made by powdering glass and then pressing it into discs with pore diameters and permeability according to B.S. specifications. They may then be fused into surrounding glass vessels.	*Borosilicate glass* (See Ovenware) Where high temperatures are involved *Fused silica* (virtually 100% SiO_2) is used.
CHEMICAL GLASSWARE: for industrial, commercial, and medical purposes	Chemical stability: so that glass does not affect nor is it affected by its contents. Mechanical strength: to carry dangerous liquids safely. Clarity: to enable flow of liquids to be clearly seen. Resistant to wide range of temperature. Resistant to thermal shock.	Tube Drawing: tubing is reheated and formed into coils, piping, and vessels, using lampworking methods on a large scale; large vessels and pipelines.	*Borosilicate glass* (See Ovenware)

PRODUCT	SPECIFIC QUALITIES	METHOD OF MANUFACTURE AND PRINCIPAL USES	GROUP AND TYPICAL FORMULA
LIGHTING GLASSWARE: **1. Electric Light Bulbs**	Economical to produce. Easy to manufacture by mass-production methods. Resistant to thermal shock. Impermeable and inert to gas, vapour, and liquid. Durable. Transparent or translucent.	Ribbon Machine: can produce bulbs at the rate of 1,000 per minute. Blanks used in the manufacture of vacuum flasks are also produced on this machine.	*Soda-lime-silica glass* % SiO_2 72·5 Al_2O_3 1·3 CaO 6·5 MgO 3·0 Na_2O 15·9 K_2O 0·3
2. Special Glasses: e.g. (a) High-pressure mercury vapour lamps	Low electrical conductivity. Resistance to intense chemical activity of hot mercury vapour.	Special glasses can be formed by usual manufacturing processes or in some cases laminated on to ordinary glasses as, for instance, sodium discharge lamps.	*Wide range of compositions*
(b) Aircraft fire-warning sensors.	Low melting point.		
(c) Glass for encapsulating electric components	High electrical conductivity.		
3. Tubing for fluorescent lighting	Low electrical conductivity. Resistance to intense chemical activity. Electrical discharge generates U.V. light which then causes fluorescent powder to emit visible light. High efficiency. Long life: 3,000–5,000 hours (i.e. about one year).	Automatic Drawing.	*Soda-lime-silica glass* % SiO_2 72·5 Al_2O_3 2·6 CaO 5·7 MgO 2·9 Na_2O 14·6 K_2O 1·2 B_2O_3 0·5
4. Domestic and industrial shades and bulkhead lights: including lenses for traffic lights, car lights, and railway signal lights	Resistant to high temperature. Resistant to thermal shock. Resistant to weathering. Accurate and non-fading colour: subject to strict B.S. specifications.	Mouth Blowing. Hand and Automatic Pressing: depending on quantities required.	*1. Soda-lime-silica glass* *2. Laminated with opal glass* *3. Borosilicate glasses and opal glasses*

PRODUCT	SPECIFIC QUALITIES	METHOD OF MANUFACTURE AND PRINCIPAL USES	GROUP AND TYPICAL FORMULA
ELECTRICAL COMPONENTS: **cathode-ray tubes, capacitors and resistors, computer components, printed circuits**	Good dielectric properties. Low electrical losses over a wide range of temperature. High operating temperatures.	Blowing. Drawing: in rod form and in sheets. Sintering and Pressing: glass is ground to fine grains and then is subsequently pressed into required shape and then fired.	*Wide range of compositions*
GLASS BUILDING BLOCKS	Resistant to normal temperature changes. Resistant to atmospheric conditions. Mechanical strength. Attractive. Translucent.	Automatic Pressing: pressed in halves and then fused together.	*Soda-lime-silica glass* Similar to flat glass
BALLOTINI: **minute glass spheres (1–60 microns) which reflect light**	High reflective properties: mixed with paint for road signs and cinema screens.	Flame Drawing: velocity of flames draws particles of glass up tower and as the softened glass falls on the outside, spheres are formed by surface tension effects.	*Soda-lime-silica glass* Similar to flat glass
GLASS FIBRE	High strength-to-weight ratio. Resistant to attack by corrosive substances. Resistant to high temperature. Flame-resistant. High electrical resistance.	Filament Drawing: Continuous Filament White Wool Crown process Can be woven into textiles or incorporated with plastics to form insulating materials, boat hulls, and car bodies, etc.	*Soda-lime-silica glass* and where resistance to weathering is necessary a *borosilicate glass* is used, e.g. % SiO_2 54·5 Al_2O_3 14·5 CaO 22·0 B_2O_3 8·5 Na_2O 0·5

Colour

Coloured glasses absorb and transmit light, ultra-violet and infra-red rays to varying degrees. Colour in glass, like its other properties, is dependent on chemical composition. There are three main divisions.

Solution

Solution: where glass acts as a solvent for certain metal oxides. The metals then show typical absorption spectra, e.g. cupric ion produces a blue colour in glass as it does in many aqueous solutions.

Opal

Opal: the result of a glass containing two phases which have differing refractive indices. There are two main types: emulsion opal (phosphate) and crystalline opal (fluoride).

Emulsions result when one liquid is finely dispersed in another liquid, the two liquids being immiscible, e.g. oil and water, and oil and vinegar. *Emulsion opal* glasses are analogous to this, e.g. a phosphate opal glass consists of a high phosphate glass dispersed in a silicate glass.

Crystalline opals result when a crystalline phase is precipitated within the glass. For example, a glass of suitable composition containing fluorides will precipitate crystals of calcium and aluminium fluorides.

Coloured opalescent glasses can be made; these are used, for example, for wall cladding and lighting glassware.

Colloidal Dispersion

Colloidal Dispersion is a two-phase system. However, in these systems the dispersed phase has a much smaller particle size than those in the opal glasses. In fact, the particles are of the same order of size as the wave-length of light. Because of this, certain wave-lengths (colours) can pass through but others will be stopped, e.g. as happens in fog when red light penetrates and blue light is stopped. Red glass, which contains a colloidal dispersion of gold, depends for its colour on these effects. Red glasses can also be made by causing a precipitate of compounds of cadmium, sulphur, and selenium.

Heat treatment is important in the development of colloidal colours. For instance, where there is a lack of concentration of the right sized particles the gold is underdeveloped and an insipid colour results. Similarly, when overdeveloped, gold particles grow too large, and a blue colour is produced.

The following table shows some colourizers:

Glass	*Colourizer*
Red	Colloidal gold, colloidal copper, and compounds of cadmium, selenium, and sulphur.
Yellow	Compounds of cadmium and sulphur.
Yellow–green	Chromium oxide, uranium.
Green	Chromium oxide, mixtures of copper and iron oxide.
Blue	Cobalt oxide, cupric oxide.
Violet	Manganese oxides.
Black	Very large amounts of colouring oxides.
Opal	Mixtures of fluoride- or phosphate-bearing minerals.

Processes applied to Formed Glass

Annealing

Glass, like most other materials, contracts on cooling. Because of its low thermal conductivity the surfaces of glass cool and therefore shrink more quickly and to a greater extent than the interior. Unchecked, this could result in uncontrolled strain in an article, which could lead to breakage. This excessive strain can be avoided by slow cooling at a controlled rate. This controlled cooling is known as *annealing*. Annealing usually takes place in an oven, or *lehr*, through which the glass articles pass on a slowly moving conveyor belt.

A container, for example, would start in the lehr at approximately 540°C. As the conveyor belt moves through the lehr, which may be up to 70 ft long, the temperature is gradually reduced. The time necessary for this operation varies with the wall thickness of the glass, e.g. for a milk bottle it might be two hours.

Toughened Glass

Useful stress can be induced by heat treatment which will enable a higher loading to be imposed on the glass. This is the *toughening* process.

Glass, like many other materials, fails in tension and fractures usually start from the surfaces. By controlled heat treatment the surface layers of glass may be put in compression with the balancing tensile forces carried by the inner sections of the glass. In this way the glass can be made to support greater loads and this material is known as toughened or *tempered* glass.

Toughening is carried out by sudden cooling of the surfaces of the glass, for example by directing blasts of air at them. Glass cannot be further processed once it has been toughened, since any disturbance of the surface will destroy the balance of stresses and cause the glass to shatter.

This process is particularly suited to strengthening flat glass and simple shapes like car windscreens or even tumblers, but is less applicable to more complicated shapes.

The surface of the glass may also be put into compression by physico-chemical methods. By ion exchange it is possible to modify the surface layer. For instance, a soda–lime–silica glass may be immersed in a molten salt (e.g. potassium nitrate) and the sodium ions exchanged for ions of a larger size. The surface of the glass may also be crystallized so that the induced crystals cause surface compression.

Surface Treatments

Coatings may be applied before, during, or after annealing to minimize surface damage and give the article better physical performance and longer service.

For example, sulphur dioxide and sulphur trioxide react with the sodium ions from the surface of the glass to form a sodium sulphate bloom which can be washed off. The remaining glass surface has a reduced alkali content and lower thermal expansion resulting in a very thin layer under compression.

Another process, which is used on glass containers, is the deposition of an inorganic oxide film, e.g. titanium, aluminium, tin, on the surface of the glass. Pyrolysis occurs and results in a scuff-resistant film. The coating gives increased surface reflection but is iridescent if too thickly applied.

Further Processes

Formed and annealed glass may be further processed. This may be done by *taking away from* or *adding to* the surface of the glass. It may also be heated, *manipulated*, and reshaped.

(i) *Taking away:* A disturbance of the surface of glass may result in a matt or obscured finish. Where a transparent surface is then required this is produced by polishing on felt or wood wheels or by a hydrofluoric acid solution.

(ii) *Adding:* Vitreous enamels, which are glasses that melt at relatively low temperature and can be coloured, may be applied to the surface of formed glass. Metal compounds can also be applied.

In both these cases the article is then reheated after the application of the enamel or metal coating so that it fuses permanently to the surface of the glass. Also, metal films can be applied by spraying, or by chemical or vapour deposition.

(iii) *Manipulating:* Glass which has been formed and annealed may be reheated and manipulated into a new shape. It then has to be re-annealed and may be toughened.

(i) Taking away

DESCRIPTION	METHOD	STAGES	USUAL TYPE OF DECORATION	TYPICAL PRODUCTS
DEEP CUTTING	Glass is ground away by holding the article against the upper edge of a large abrasive wheel.	Marking. Rough grinding. Smooth grinding. Polishing.	Formal, geometrically based designs. Usually polished.	Domestic glassware, especially Full Lead Crystal. Flat glass decorative mirrors, etc.
INTAGLIO CUTTING	Lighter grinding by holding the upper surface of the article against the lower edge of a small abrasive wheel.	Marking. Grinding. Polishing.	Freer designs, e.g. scrolls, but with a definite rhythm. Often unpolished.	Domestic glassware, especially Full Lead Crystal.
COPPER WHEEL ENGRAVING	Light grinding by holding the article against the lower edge of a copper wheel on to which an abrasive is fed. A variety of sizes of wheel is used for different depths and widths of pattern.	Marking. Grinding.	Pictorial treatments, lettering. Seldom polished.	Domestic glassware, especially Full Lead Crystal: generally for individual pieces, commemorative and special glassware.
DIAMOND POINT ENGRAVING	Scratching on surface of glass with a diamond or tungsten carbide pointed stylus. The latter is more usual now.	Marking often on guide chart. Scratching or stippling.	Pictorial treatment, lettering. Never polished.	Full Lead Crystal: commemorative and special glasses.
GRINDING	Flat glass surfaces are pressed on to a revolving grinding table. Curved surfaces are ground on a lathe.			Desiccator lids. Jar stoppers. Ground glass joints for laboratory ware.

DESCRIPTION	METHOD	STAGES	USUAL TYPE OF DECORATION	TYPICAL PRODUCTS
SANDBLASTING	Surface of the glass is removed by blowing a jet of abrasive against it by compressed air. Portion of the glass to be left plain is covered with a resistant material. Small articles are held in a sandblasting cabinet which protects the operator. Flat glass is blasted with a spray gun, the operator wearing a mask, goggles, gloves, and other protective clothing.		Lettering for permanent labels. Badging for permanent identification. Geometrical and pictorial decoration.	Labels for containers, especially chemical, which are often enamelled afterwards. Domestic and catering glassware. Decorated and lettered flat glass, including mirrors.
ACID ETCHING	Immersion in solutions containing hydrofluoric acid. Patterns obtained by covering the glass with a wax resist to protect areas from being etched.	Overall: Flat glass dipped in acid. Electric lamp bulbs filled with acid which is then drained off. Pattern: Application of wax resist. Immersion in acid wash.	Translucency: total and partial.	Flat and hollow glassware, e.g. lighting shades and pearl electric lamp bulbs. Domestic glassware.

(ii) Adding

DESCRIPTION	METHOD	STAGES	USUAL TYPE OF DECORATION	TYPICAL PRODUCTS
FUSING	Glasses of different compositions and colours can be fused together. Great care is necessary because of the varying coefficients of expansion and contraction of different glasses.	Placing. Firing.		Glass-to-glass seals for electrical, medical, and industrial components. Wall panels. Decorative tiles.
VITREOUS ENAMELLING	Can be applied either as a liquid suspension: 1. Freehand 2. Screen printing 3. Spraying or dry in form of transfer.	Application. Firing.		Stained-glass windows. Glass containers. Ampoules and vials. Domestic glassware. Ashtray advertisements. Architectural glass.
METAL COATING	Sprayed or poured on to the glass and sealed with lead sulphide film or with electroplated copper. 1. Chemical deposition: total immersion. As a result of the chemical reaction taking place the metal is firmly deposited on the surface of the glass.	Cleaning and pretreatment of surface of glass. Deposition. Application of protective backing.	Total.	Mirrors—decorative panels, etc.
	2. Fired-on films: Freehand Screen printing Spraying.	Application. Firing.	Total and partial.	Domestic glassware. Containers.
	3. Vapour deposition: Deposition of thin films of metals or minerals in vacuum or in controlled atmospheres.			Non-reflecting optical components (bloomed lenses). Surface-treated glass containers. Electrically conductive films, e.g. de-icing windscreens.

(iii) Manipulating

DESCRIPTION	METHOD	STAGES	TYPICAL PRODUCTS
LAMPWORKING	1. Manual: Glass is heated over gas, air/coal gas, or oxy/coal gas flame, and refashioned by localized blowing and manipulation with tools.	Heating. Manipulating. Cooling. Annealing.	Laboratory equipment. Thermometers. Glass animals. Glass eyes. Discharge signs.
	2. Machine: Automatic and hand-operated machinery is used for manipulating the glass in the flames.	Heating. Manipulating. Cooling. Annealing.	Ampoules and vials. Vacuum flasks.
MANIPULATING FLAT GLASS	Cut to shape, reheated, and reshaped in moulds.		Curved windows, windscreens, roof domes, etc. Domestic glassware.

Glass and Other Materials

Glass-to-Metal Seals

Glass when heated can be made to fuse impermeably to metals. In forming a seal the characteristics of the metal and the glass at all operating temperatures must be taken into account. In particular, either the thermal expansion coefficients must be compatible to avoid stress (*matched* seals), or the metal section must be thin enough to compensate through its plastic flow for the differential expansion between glass and metal (*mismatched* seals). Examples of the use of these seals can be seen in television tubes, electronic valves, discharge lamps, sealed-beam headlamps, and electric light bulbs. Glass-to-ceramic seals can be formed where there is matched thermal expansion.

Laminates

Glass can also be laminated with other materials. For instance, some windscreens are made from a laminated safety glass made up of two layers of glass with a plastic sheet in between. If the glass breaks the pieces still adhere to the sandwich material. Safety goggles are also made of this form of glass laminate. Glass fibres are also used as reinforcement for plastics materials, e.g. boat hulls and chairs.

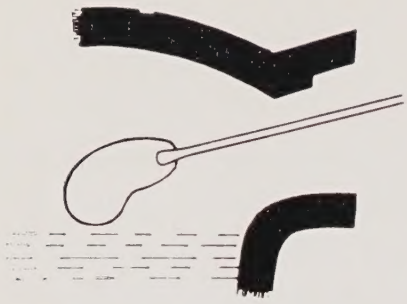
Glass Ceramics

These are a new family of non-metallic materials. The non-porous crystalline material is formed from glasses (which are non-crystalline) which contain nucleating agents uniformly distributed. When the glass is heated or irradiated these are converted into billions of sub-microscopic crystallites which each act as a centre of crystal growth.

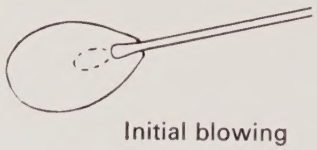
The resulting crystalline structure is much finer than conventional ceramics and the material is much harder than most metals and the parent glass.

Like conventional glasses, glass ceramics can be made to incorporate different properties as required. Present uses include rocket nose-cones, refrigerator-to-stove table ware, laboratory ware, and cements for sealing metal to metal, glass to glass, and glass to metal.

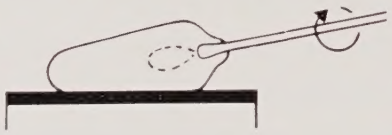
Making Domestic Glass by Hand



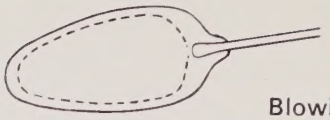
Gathering glass on blowing iron



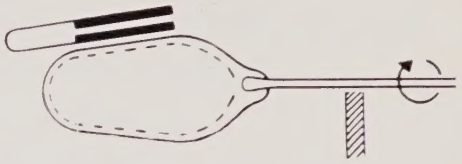
Initial blowing



Marvering

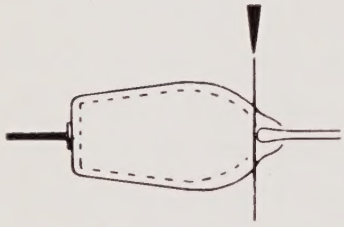


Blowing parison



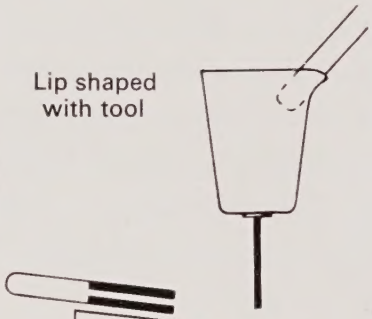
Shaping bowl with tool

Shaping base

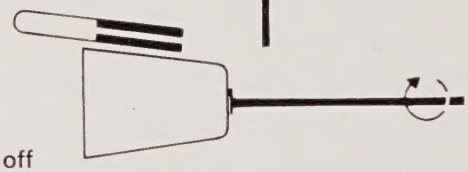


Attaching pontil at base—
blowing iron cracked off

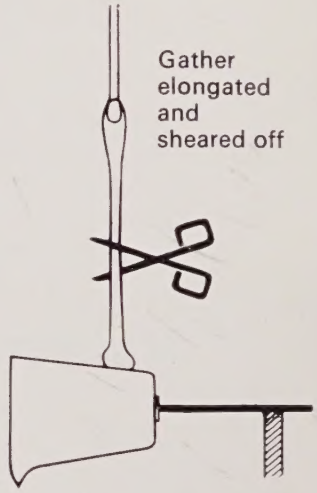
Top sheared off
to correct height



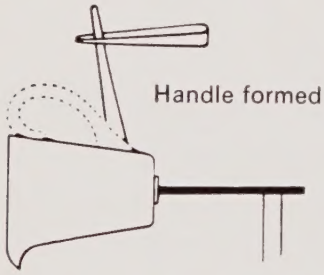
Lip shaped
with tool



Shape of bowl completed



Gather
elongated
and
sheared off



Handle formed with tool

Molten glass is gathered from the pot on the end of a hollow blowing iron. After being initially blown the gather is marvered (rolled on a smooth slab). Whilst the glass is being shaped by alternate blowing and tooling, the blowing iron is constantly rotated on the arm of the glassmaker's chair to keep the shape symmetrical. When the base has been shaped, the pontil (solid rod) is attached to it with a small amount of glass and the top of the article scored round below the blowing iron and cracked off. After reheating in a furnace known as the gloryhole, the top is sheared off, tooled and finished, completing the bowl. A lip is shaped with a round cylindrical tool. Separate gathers of glass are dropped on and handles, stems or feet are formed. The pontil is cracked off the finished article which is taken away to the annealing lehr. The glass is reheated from time to time during the working period.

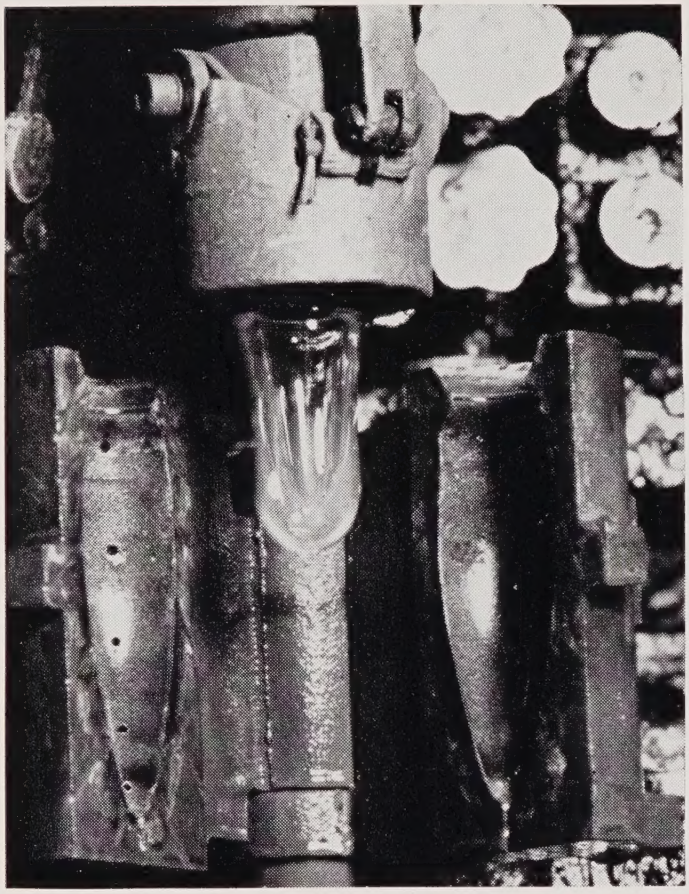
Blowing the bowl of a wine glass.

The decoration is "deep cut" by holding the jug against the upper edge of an abrasive wheel.

"Intaglio" is a lighter form of decoration. The bowl is held against the lower edge of an abrasive wheel.

Engraving, carried out by holding the vase against the lower edge of a copper wheel on to which an abrasive is fed.

Making Domestic Glass by Machine



The mould closes round a gob of glass which is blown into the shape of the bowl.

A second gob of glass drops into a mould on the bowl, which has been inverted, to form the stem and foot.

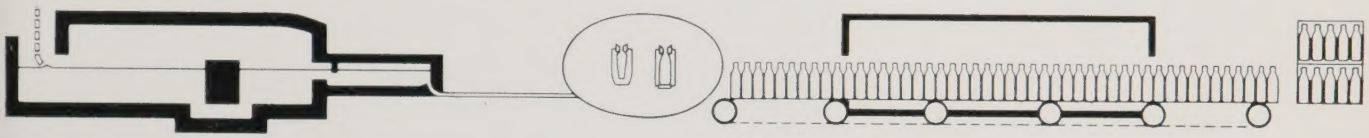
The mould opens to show the almost completed glass. Subsequently the foot is heated and formed and the rim of the glass smoothed.

Making Glass Containers by Automatic Process

Raw materials are automatically mixed and fed into the furnace where they are heated and fused at 1350°–1450°C.

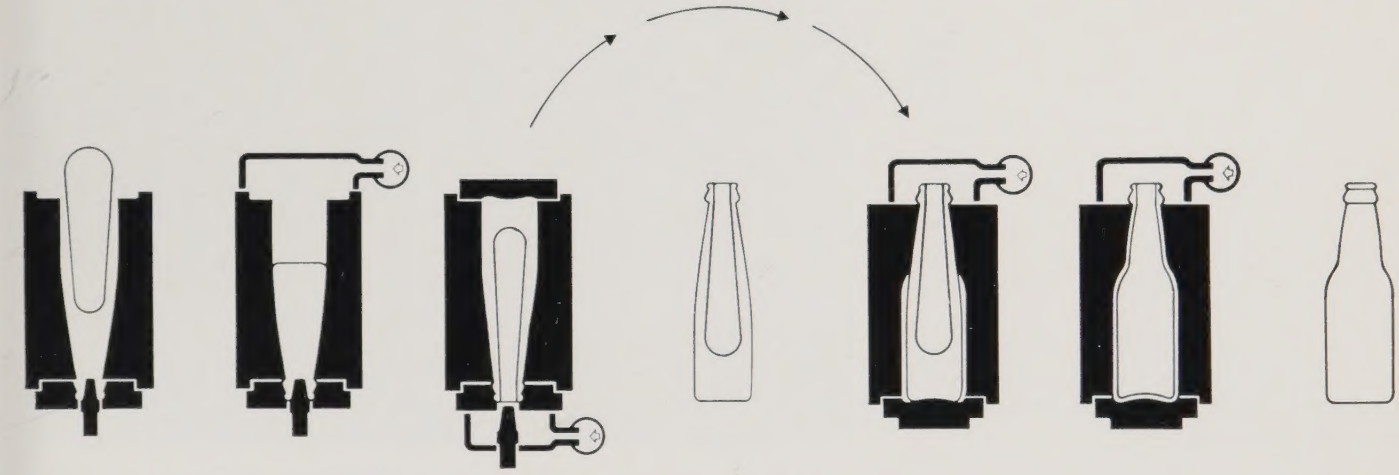
Molten glass is fed into a machine where it is automatically blown. Bottles are made in two stages. First a parison shape is blown. This is transferred to a second mould in which the bottle is blown to its final form.

Bottles are inspected and despatched for subsequent filling, capping and labelling.



Glass Melting Furnace

Annealing lehr in which bottles are reheated and gradually cooled to prevent stresses developing.



1 Gob Dropped into Blank Mould

2 Neck Formed

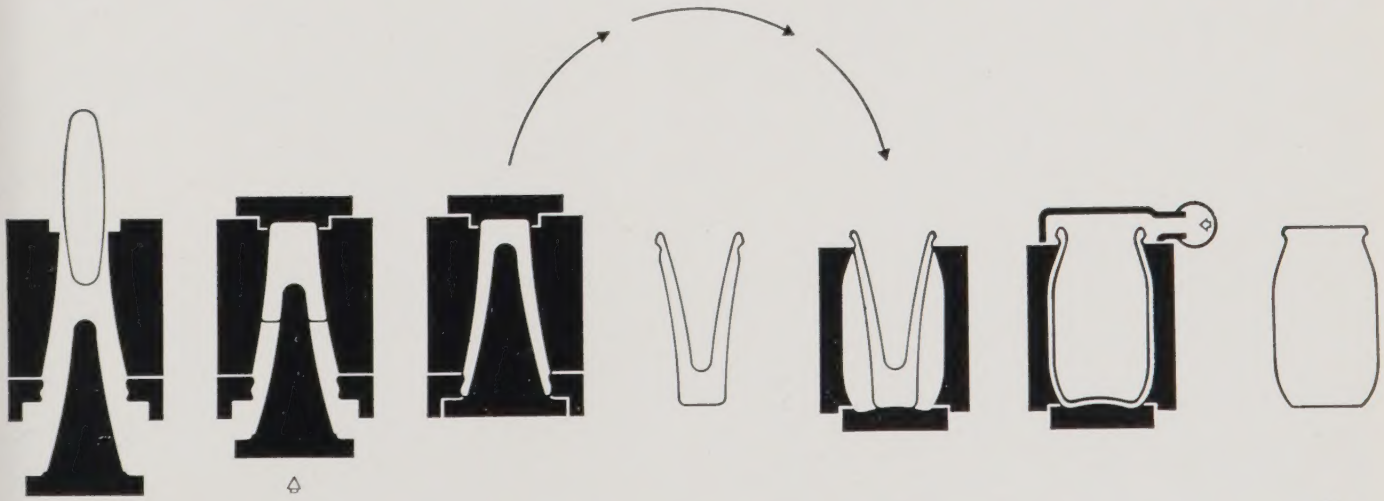
3 Blank Blown

4 Blank Shape

5 Blank Transferred to Blow Mould

6 Final Shape Blown

7 Finished Bottle



1 Gob Dropped into Blank Mould

2 Plunger Presses Blank Shape

3 Blank Pressed

4 Blank Shape

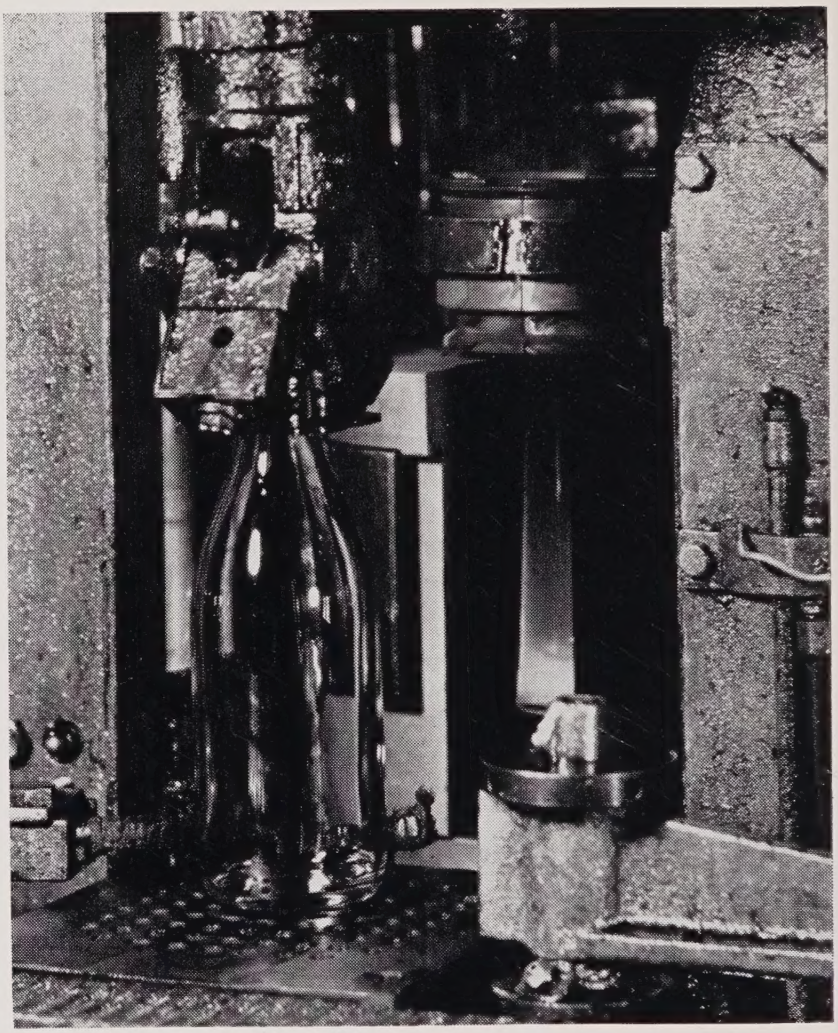
5 Blank Transferred to Blow Mould

6 Final Shape Blown

7 Finished Jar

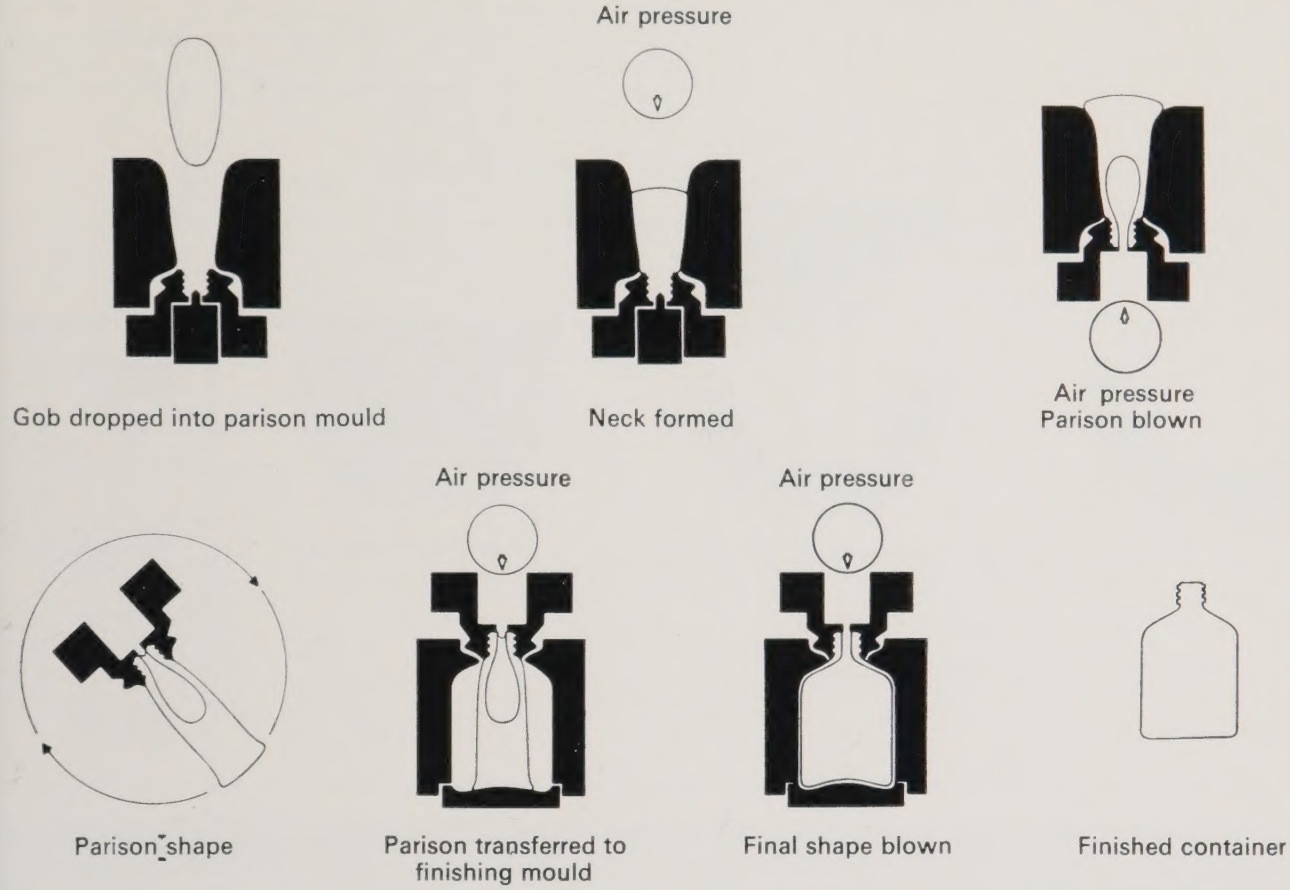
Making Glass Containers

A milk bottle has just been blown. In the background the parison is being transferred from the blank mould to the blow mould.

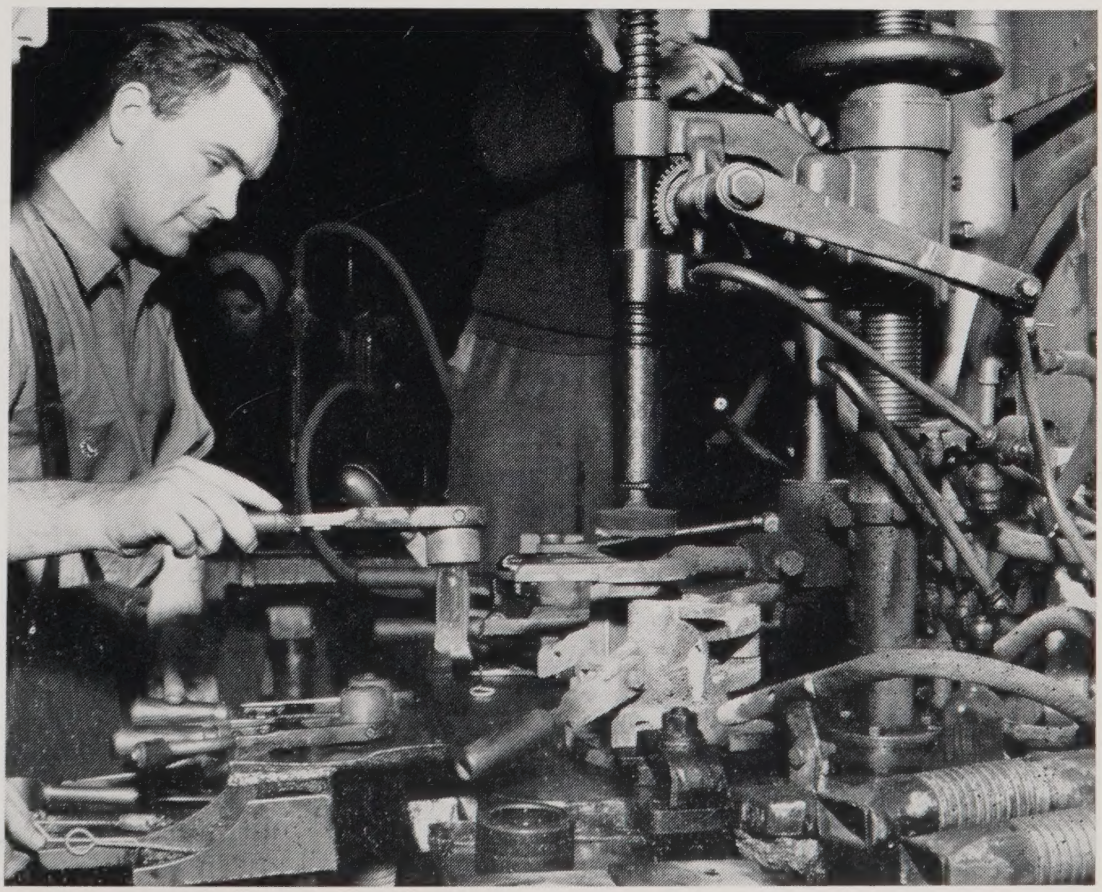


Inspecting finished bottles as they emerge from the annealing lehr.

Making Glass Containers by Semi-automatic Process



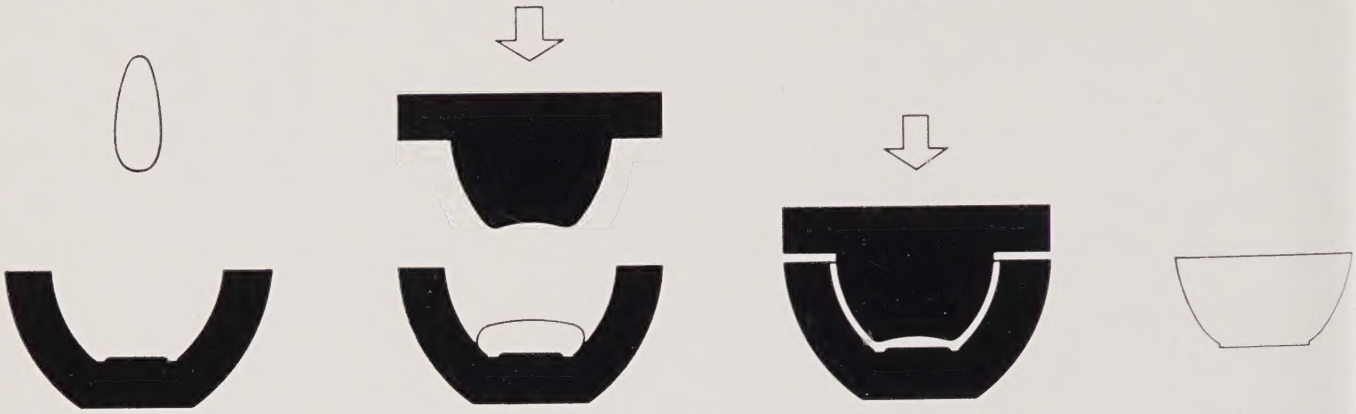
The gob is gathered by hand on an iron, and the correct amount of glass is dropped into a preliminary mould. Compressed air is introduced to form the neck of the article. The embryo shape (parison) is then transferred to the finishing mould in which the final shape is blown.



In the semi-automatic process the container is transferred from the blank mould to the blow mould by hand.

Making Pressed Glass

Correct amount of glass is dropped into the mould. In hand production, the glass is gathered on an iron. In automatic production, the gob is extruded, sheared off and drops into the mould. The plunger descends to press the final shape.



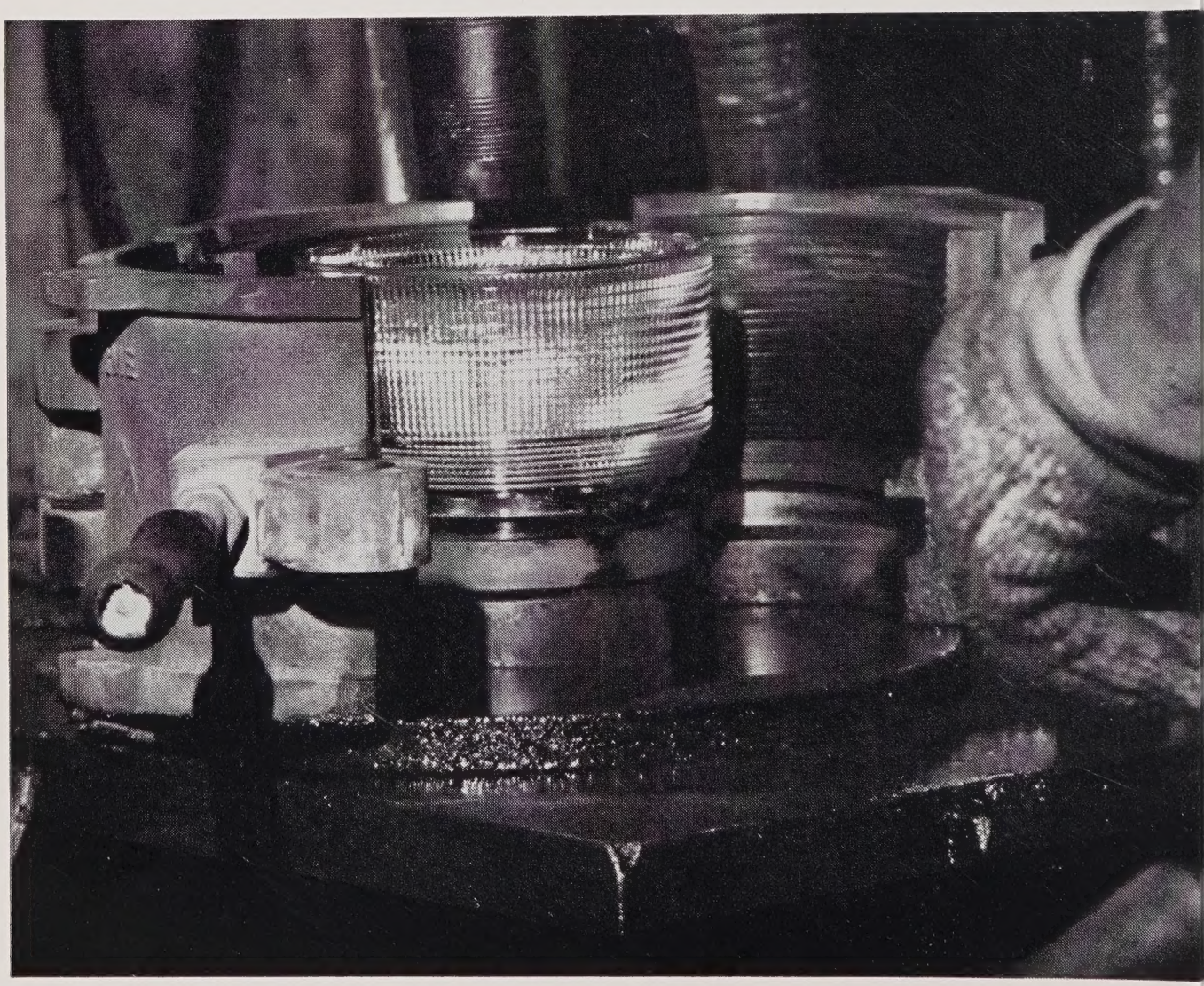
Gob drops into mould

Gob settles and plunger descends

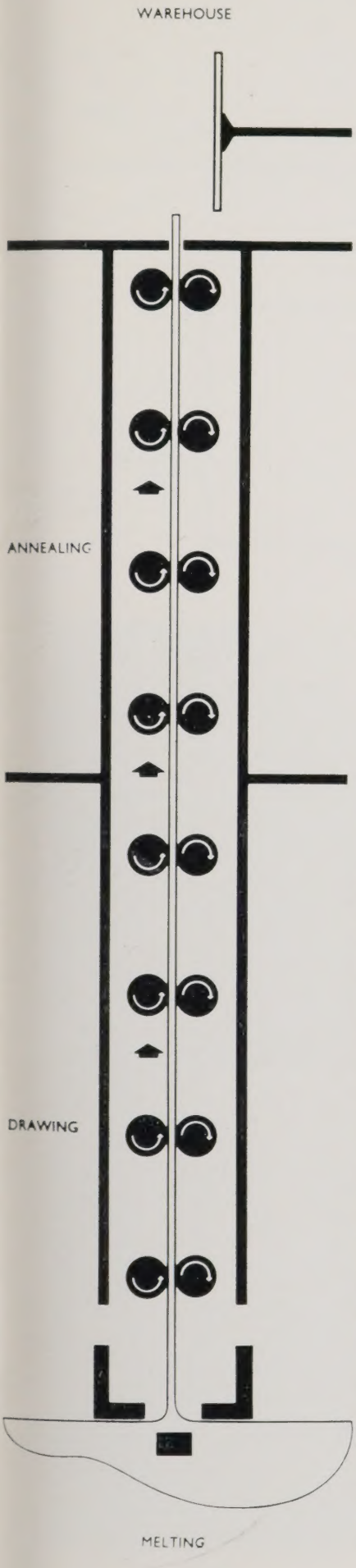
Final shape pressed

Finished product

The plunger has been withdrawn and the mould opened so that the article, a lamp cover, can be removed.

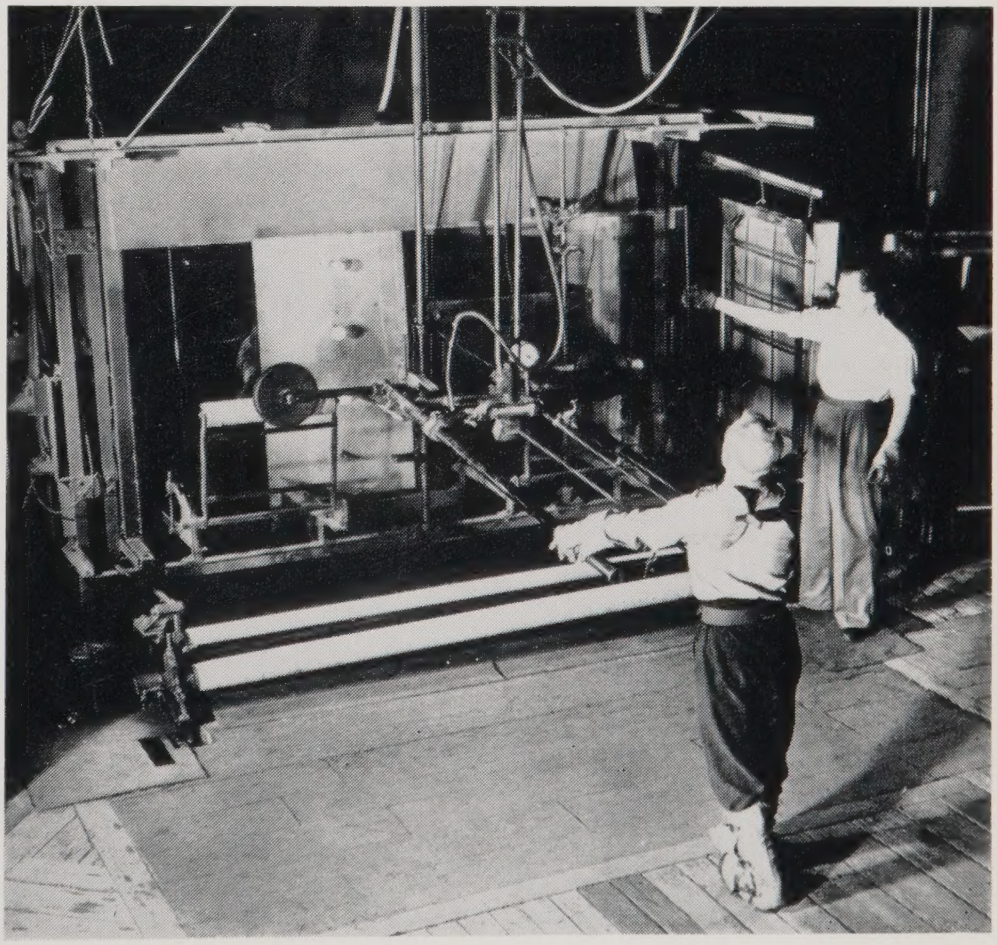


Making Sheet Glass

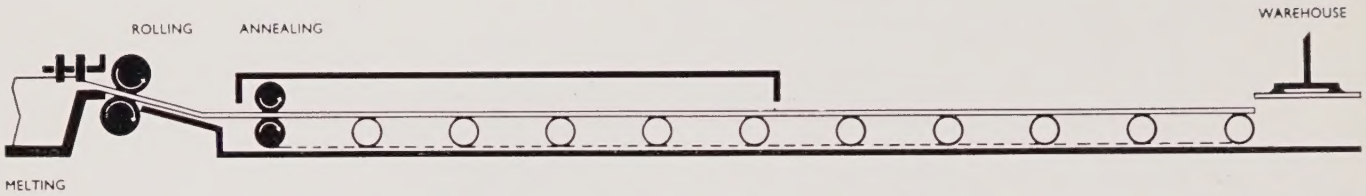


A bait dipped into the molten glass is used to start a continuously rising ribbon of glass. The rate of drawing determines thickness. Small rollers grip the edges of the glass keeping the width constant. Annealing takes place in the tower and the glass is cut off to required lengths at the top.

A sheet of glass has been cut from the continuously rising ribbon of glass. It is removed by means of an electrically operated suction machine.

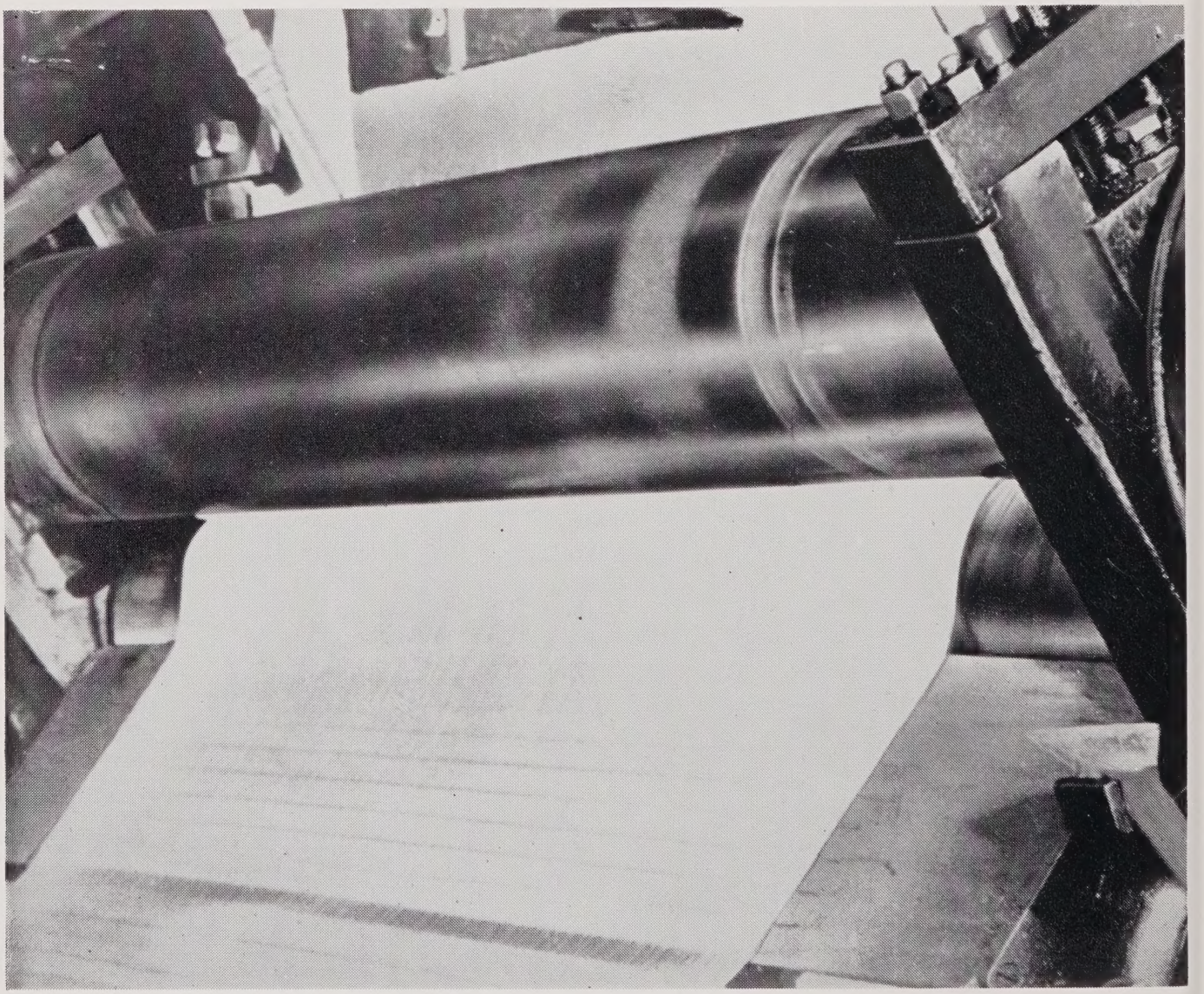


Making Figured Glass



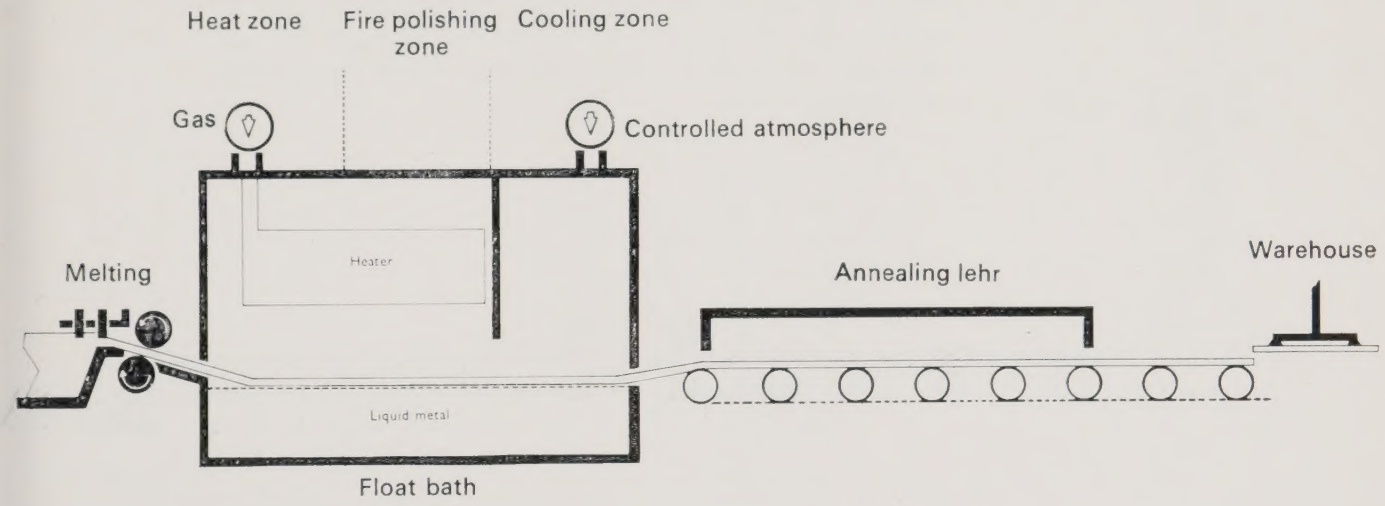
Molten glass flows continuously between water-cooled rollers which are embossed to form a pattern on the glass. The rate of drawing determines thickness. After annealing the glass is cut off to required lengths.

The sheet of glass is extruded between rollers. One or both rollers may be embossed to give the pattern or "figure" to the glass.

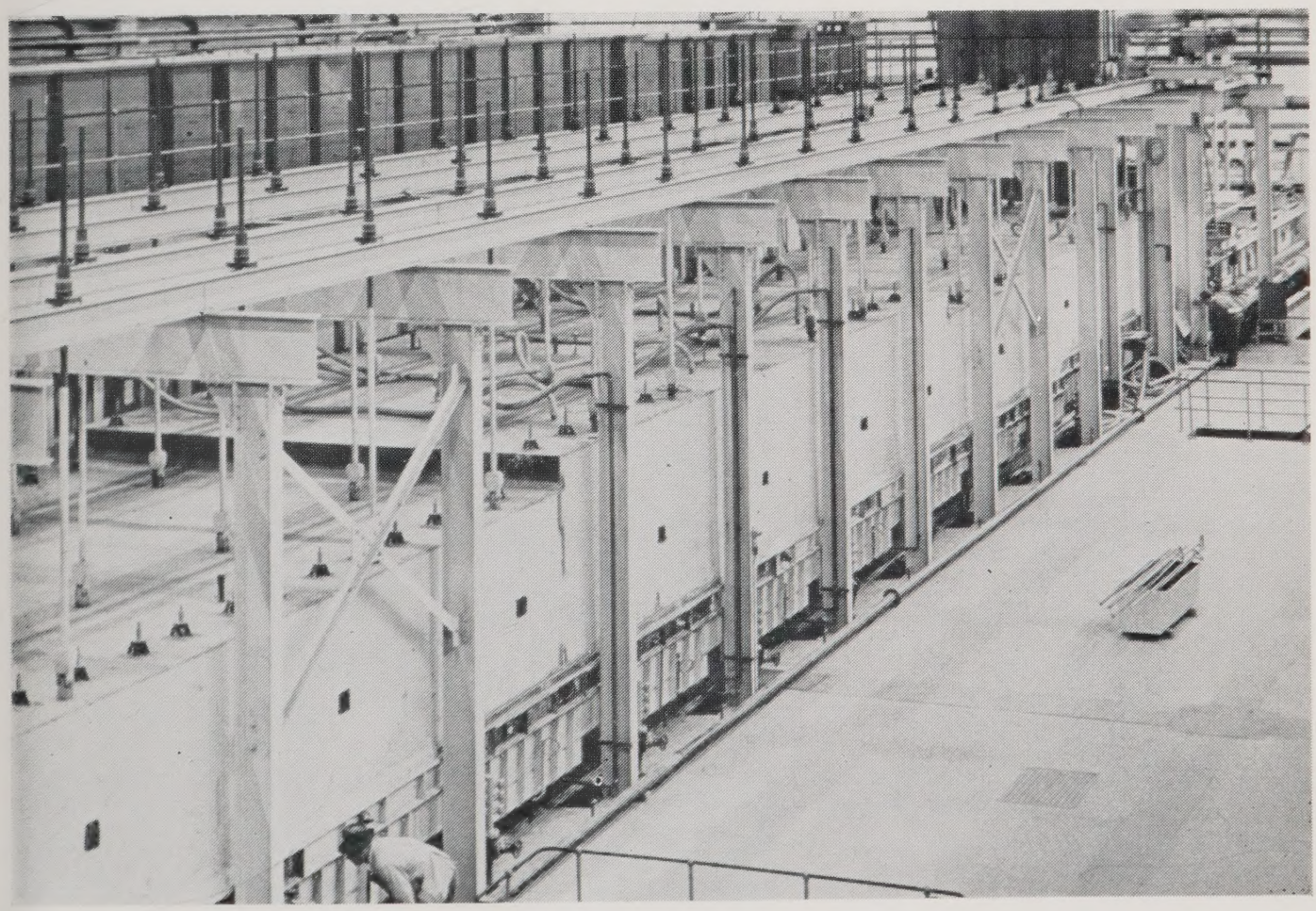


Making Float Glass

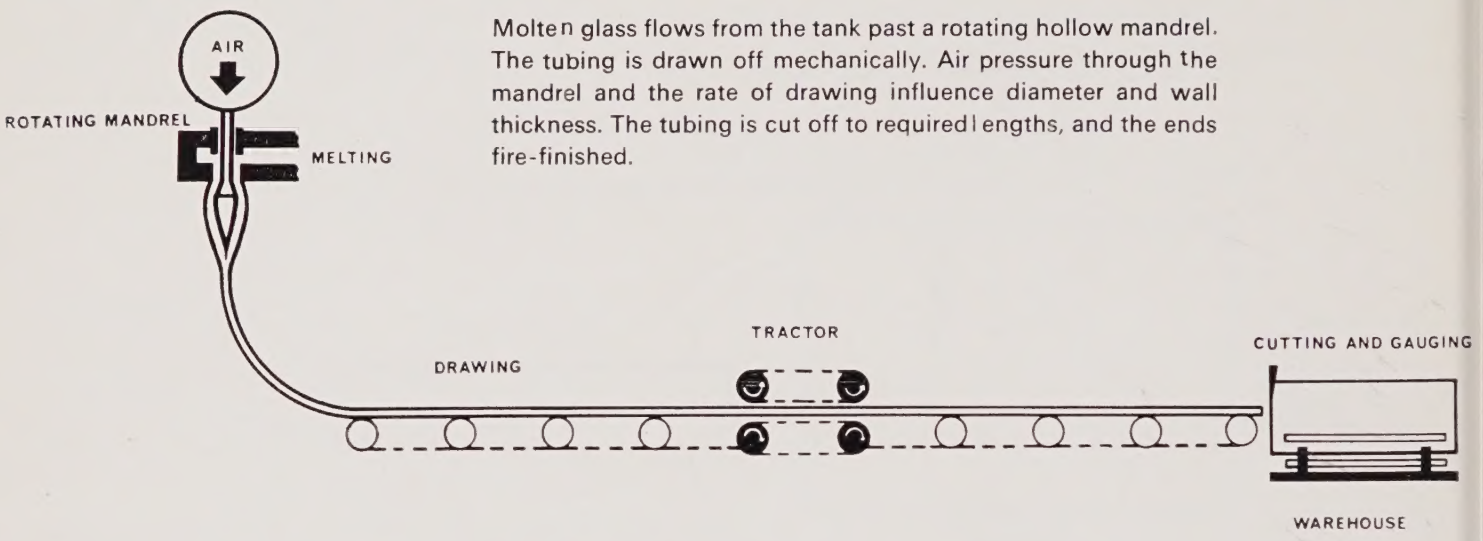
Molten glass flows from the tank in a continuous ribbon to float on the surface of liquid tin at a carefully controlled temperature. The parallel brilliant surfaces produced make grinding and polishing unnecessary. After annealing the glass is cut off to required lengths.



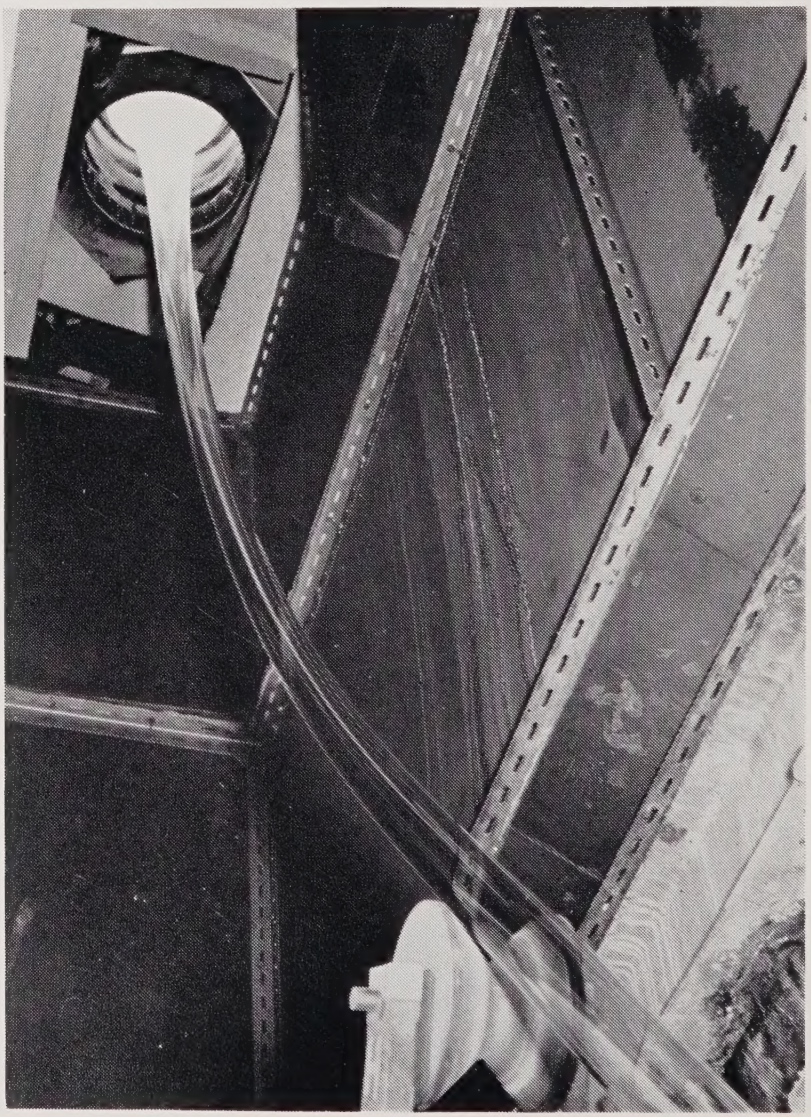
A general view of the bath on which the glass floats.



Making Glass Tubing

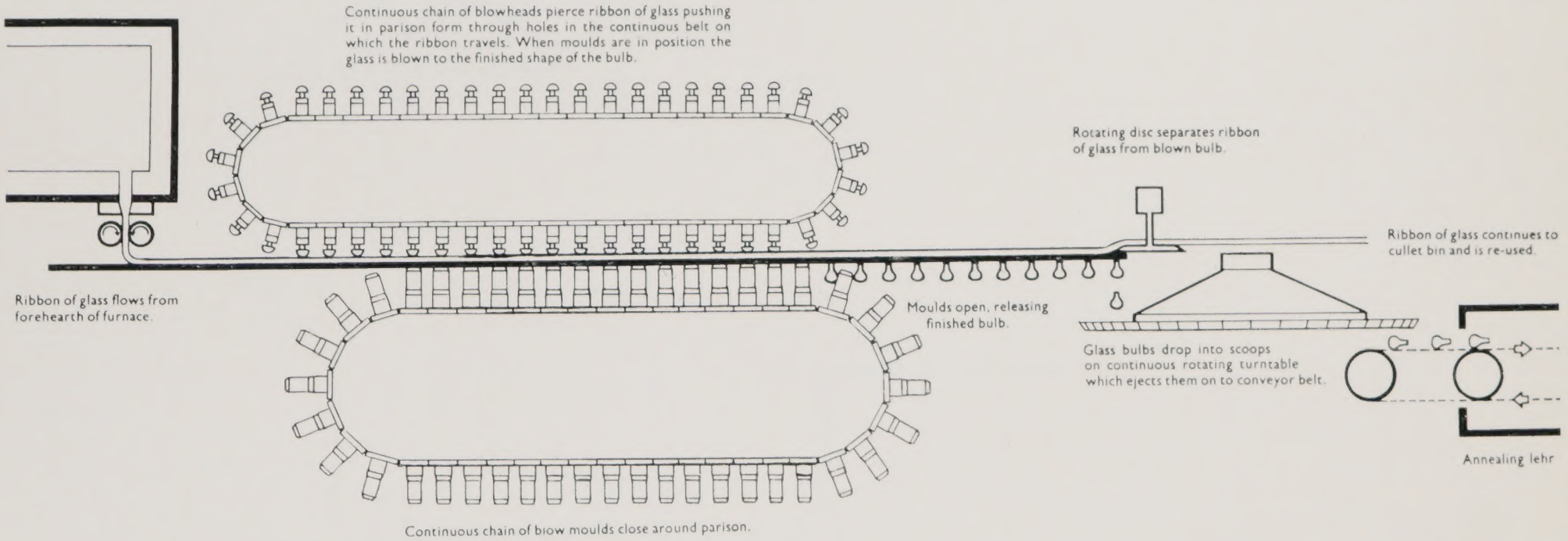


Molten glass flows from the tank past a rotating hollow mandrel. The tubing is drawn off mechanically. Air pressure through the mandrel and the rate of drawing influence diameter and wall thickness. The tubing is cut off to required lengths, and the ends fire-finished.



Glass tubing is formed over a rotating mandrel.

Making Electric Light Bulbs

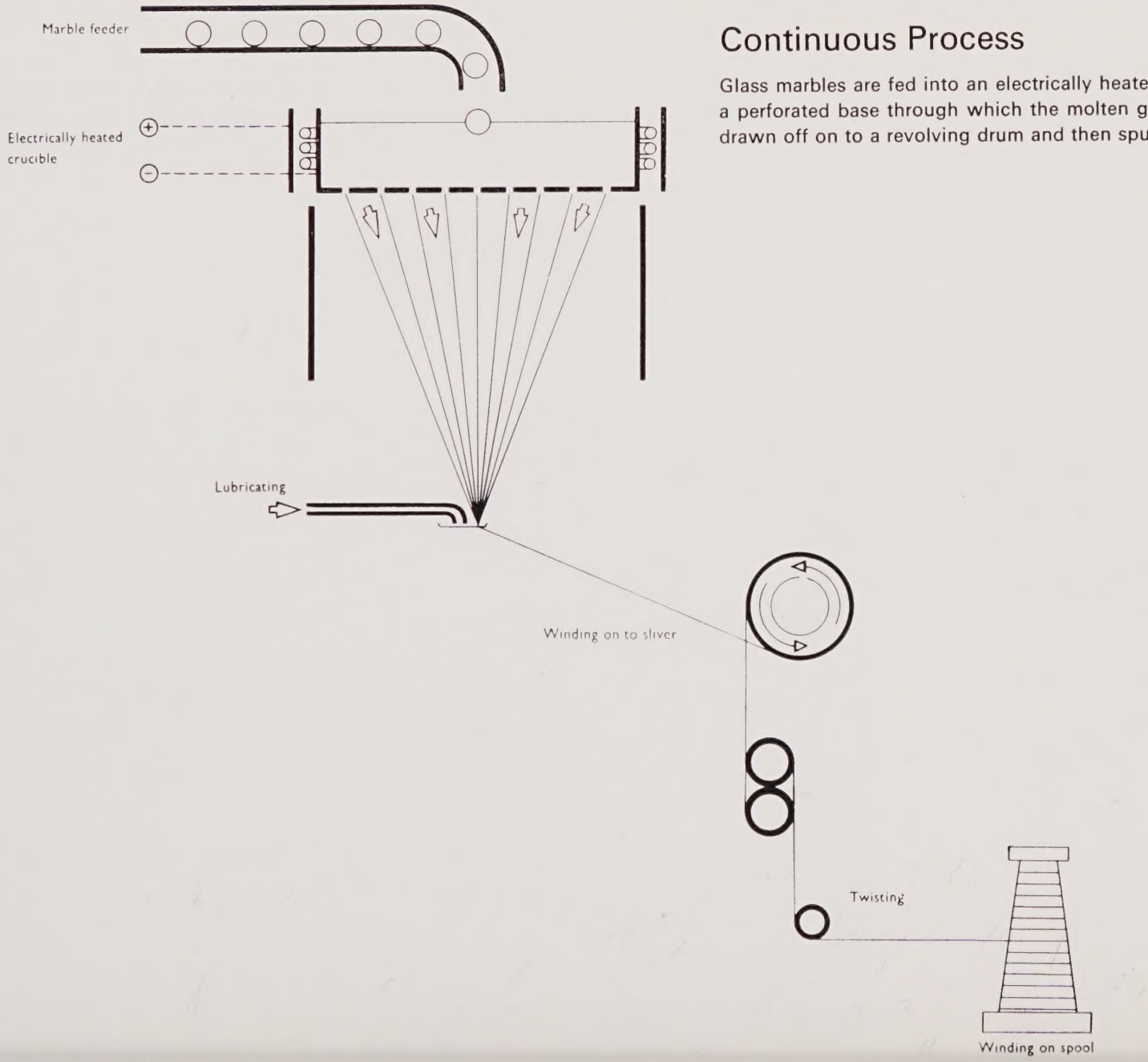

Continuous chain of blowheads pierce ribbon of glass pushing it in parison form through holes in the continuous belt on which the ribbon travels. When moulds are in position the glass is blown to the finished shape of the bulb.
Rotating disc separates ribbon of glass from blown bulb.
Ribbon of glass continues to cullet bin and is re-used.
Ribbon of glass flows from forehearth of furnace.
Moulds open, releasing finished bulb.
Glass bulbs drop into scoops on continuous rotating turntable which ejects them on to conveyor belt.
Annealing lehr
Continuous chain of blow moulds close around parison.

Molten glass flows continuously between water-cooled rollers and the ribbon so formed is carried forward on orifice plates. Blowheads from above blow the glass through the holes in the plates. Moulds from below meet and close around these "blisters". The moulds fall away revealing the formed bulbs which are cooled by air jets and tapped off the ribbon. They fall into scoops on the rotary turntable which tip them on to the conveyor belt to the annealing lehr. Up to 2,000 bulbs per minute can be produced on such a machine.

Making Glass Fibre

Continuous Process

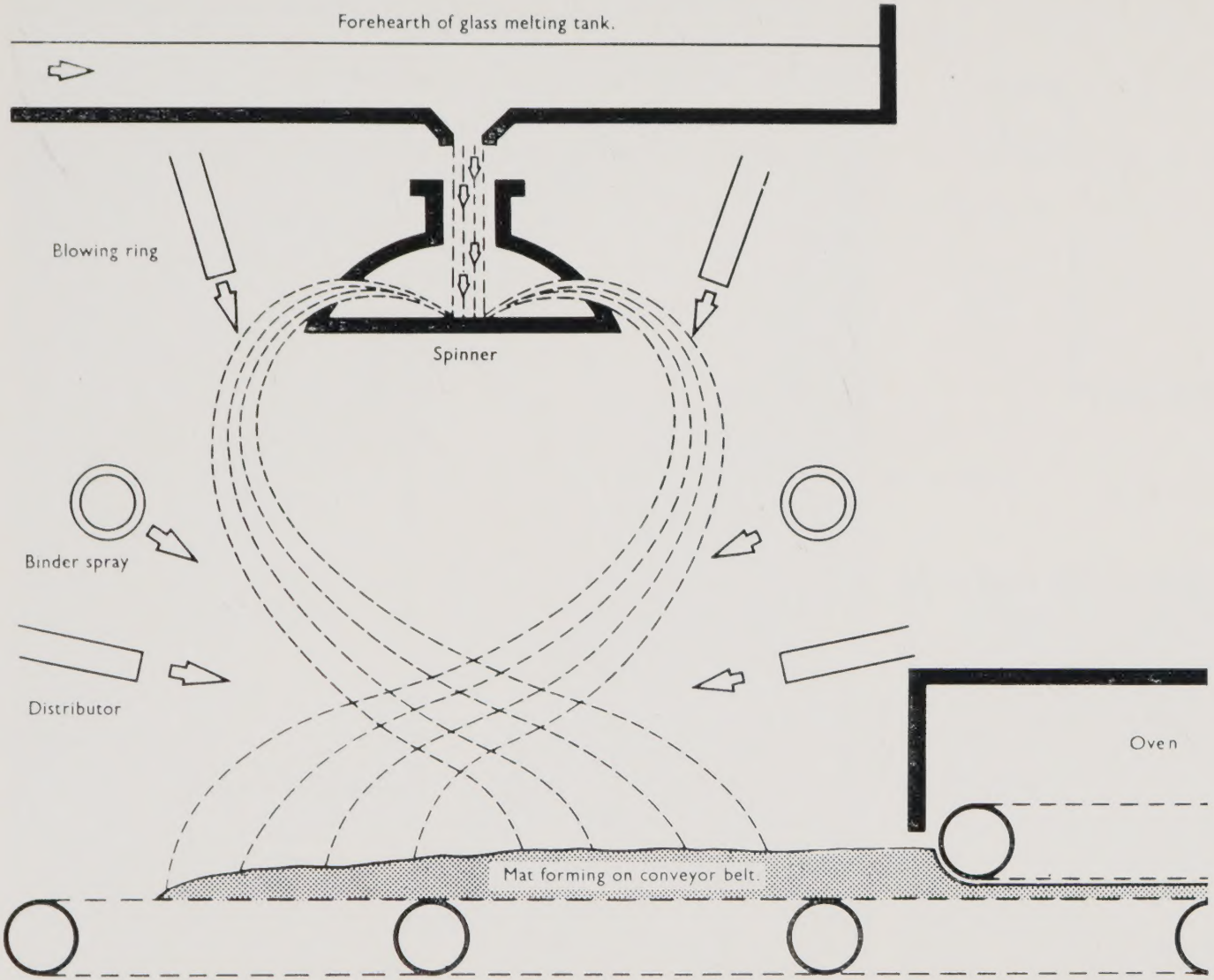
Glass marbles are fed into an electrically heated platinum crucible with a perforated base through which the molten glass drips. The fibres are drawn off on to a revolving drum and then spun.



Making Glass Fibre

Crown Wool Process

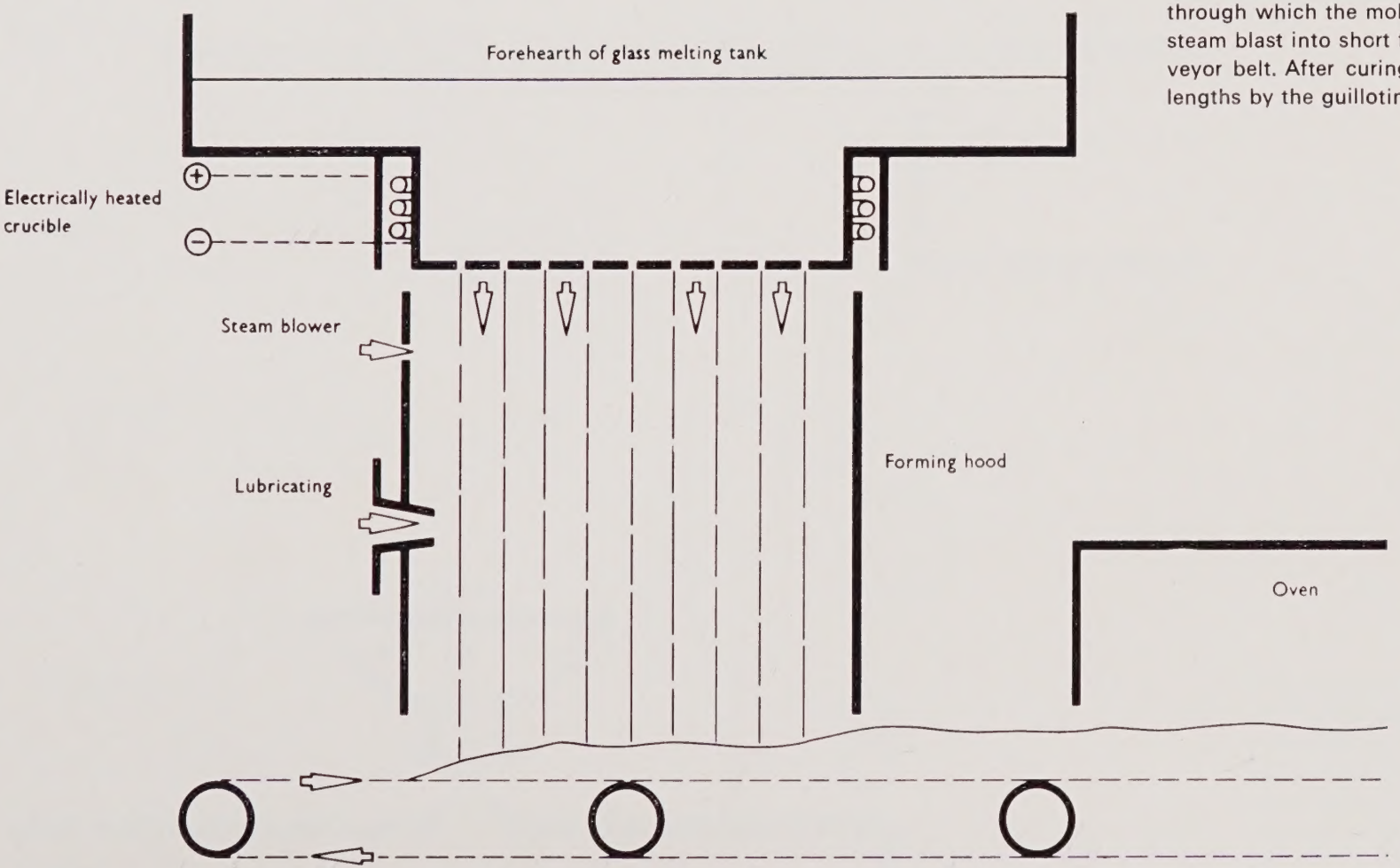
Glass flows from the forehearth of the melting tank into a rotating perforated spinner which forms it into very firm fibres by a centrifugal process. The fibres are sprayed with a binding agent and further agitated so that they fall at random to form a mat on the conveyor belt. After curing, the width of the mat is determined by slitters and it is cut into varying lengths by the guillotine and automatically rolled into bales.



Making Glass Fibre

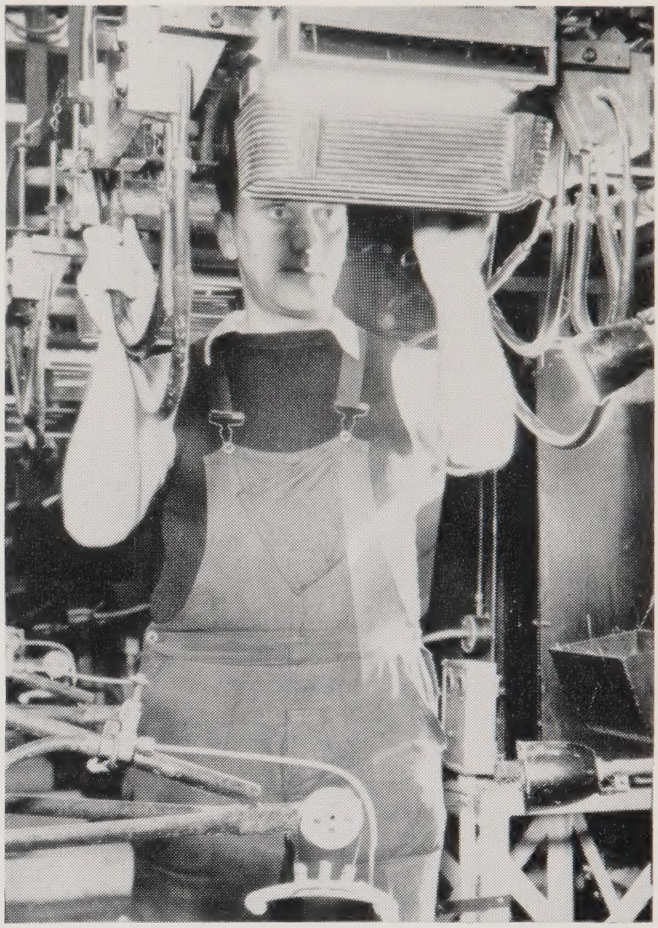
White Wool Process

Glass is fed from the forehearth of the melting tank into an electrically heated platinum crucible with a perforated base through which the molten glass flows. It is shattered by a steam blast into short fibres which form a mat on the conveyor belt. After curing the mat is automatically cut into lengths by the guillotine.

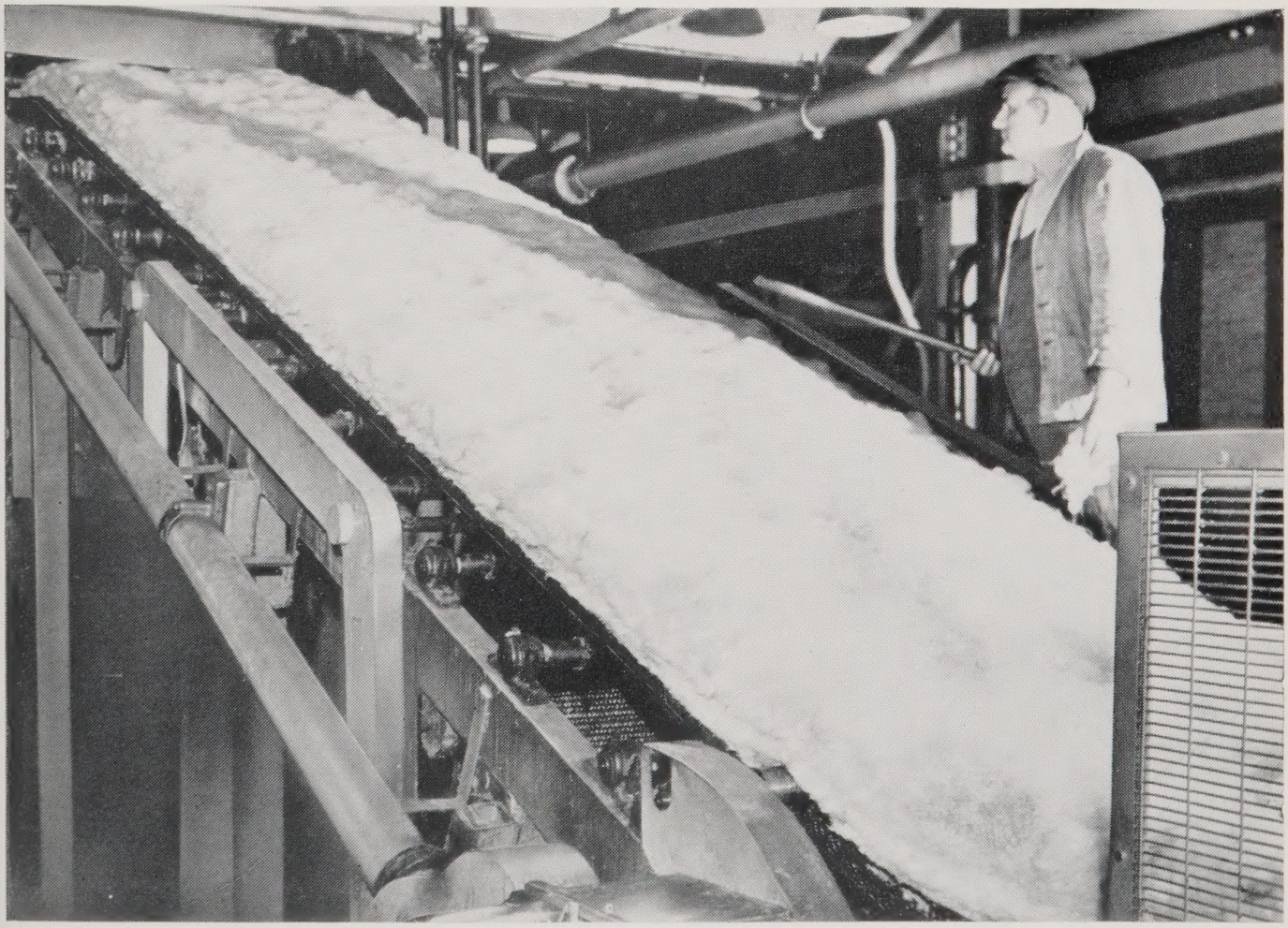


Making Glass Fibre

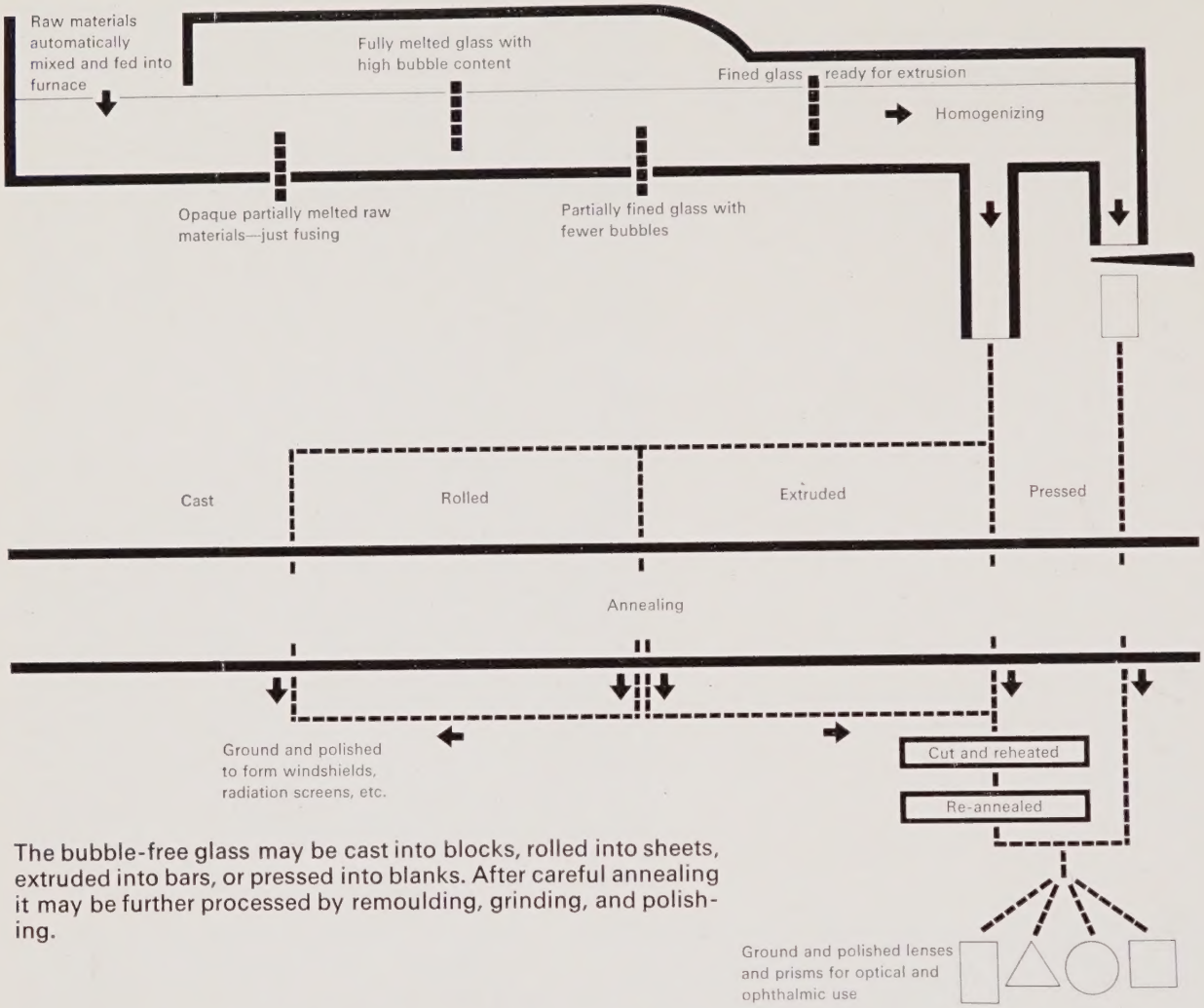
Glass fibres are drawn from the perforated base of the crucible in which the glass is melted.



Short fibres are sprayed with a binding agent and fall on to a conveyor belt to form a mat.

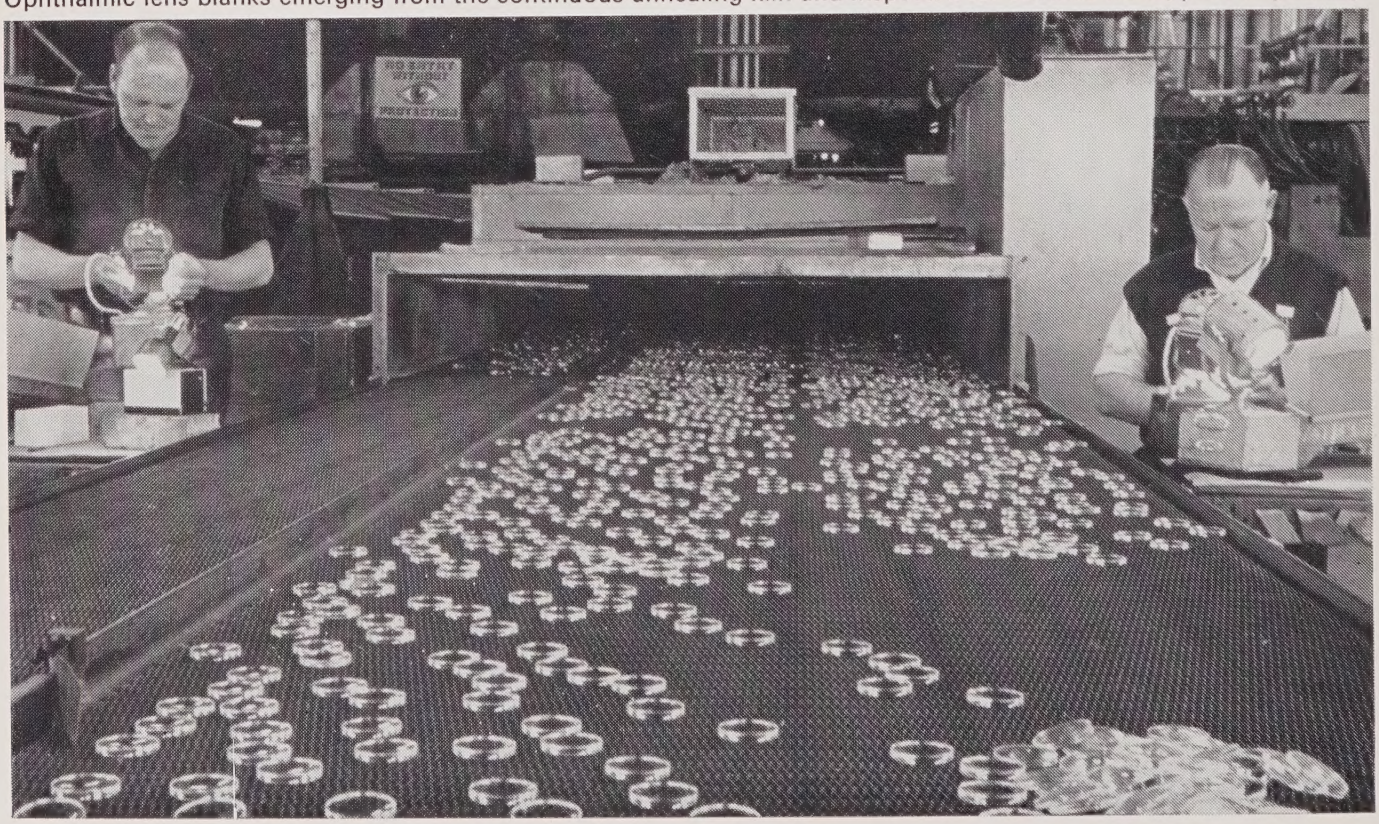


Continuous Optical Process


Raw materials automatically mixed and fed into furnace
Fully melted glass with high bubble content
Fined glass ready for extrusion
Homogenizing
Opaque partially melted raw materials—just fusing
Partially fined glass with fewer bubbles
Cast
Rolled
Extruded
Pressed
Annealing
Ground and polished to form windshields, radiation screens, etc.
Cut and reheated
Re-annealed
Ground and polished lenses and prisms for optical and ophthalmic use

The bubble-free glass may be cast into blocks, rolled into sheets, extruded into bars, or pressed into blanks. After careful annealing it may be further processed by remoulding, grinding, and polishing.

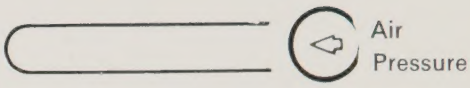
Ophthalmic lens blanks emerging from the continuous annealing kiln and inspected for obvious faults, prior to packing.



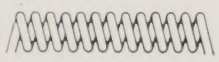
Lamp Working

Raw materials are pieces of tubing of different diameters and wall thicknesses.

Tubing for jacket is heated and drawn apart.

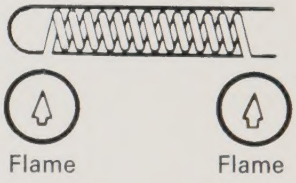


End is sealed and rounded off by applying air pressure at the opposite end.

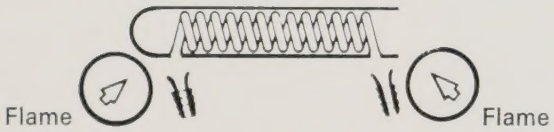


For the internal spiral tubing is heated and formed.

Spiral is placed inside jacket.

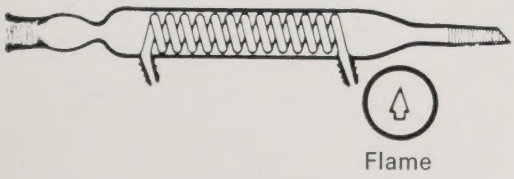


Jacket heated and holes formed at intersections with spiral.



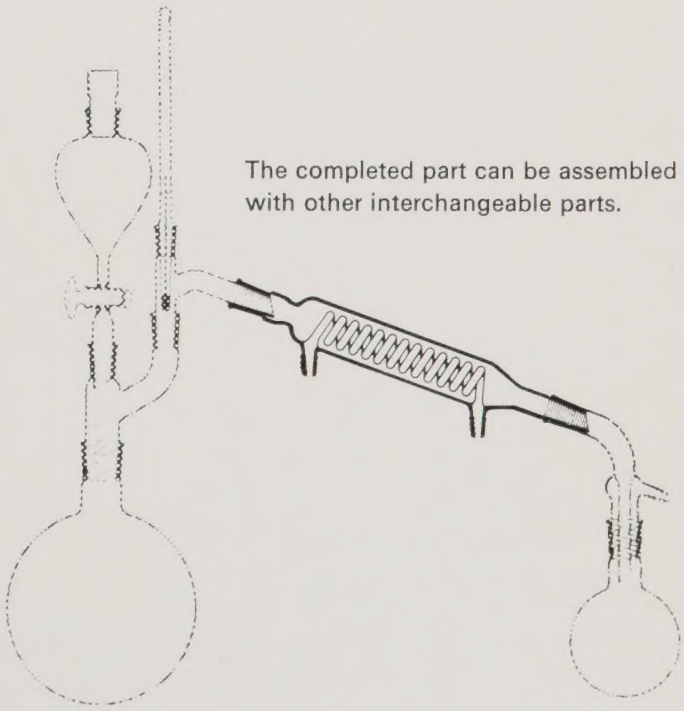
Small pre-formed tapered pieces are fused on at these points as inlet and outlet openings. Spiral is sealed to jacket wall.

Pre-shaped end piece made of tubing and internally ground is fused to sealed end.



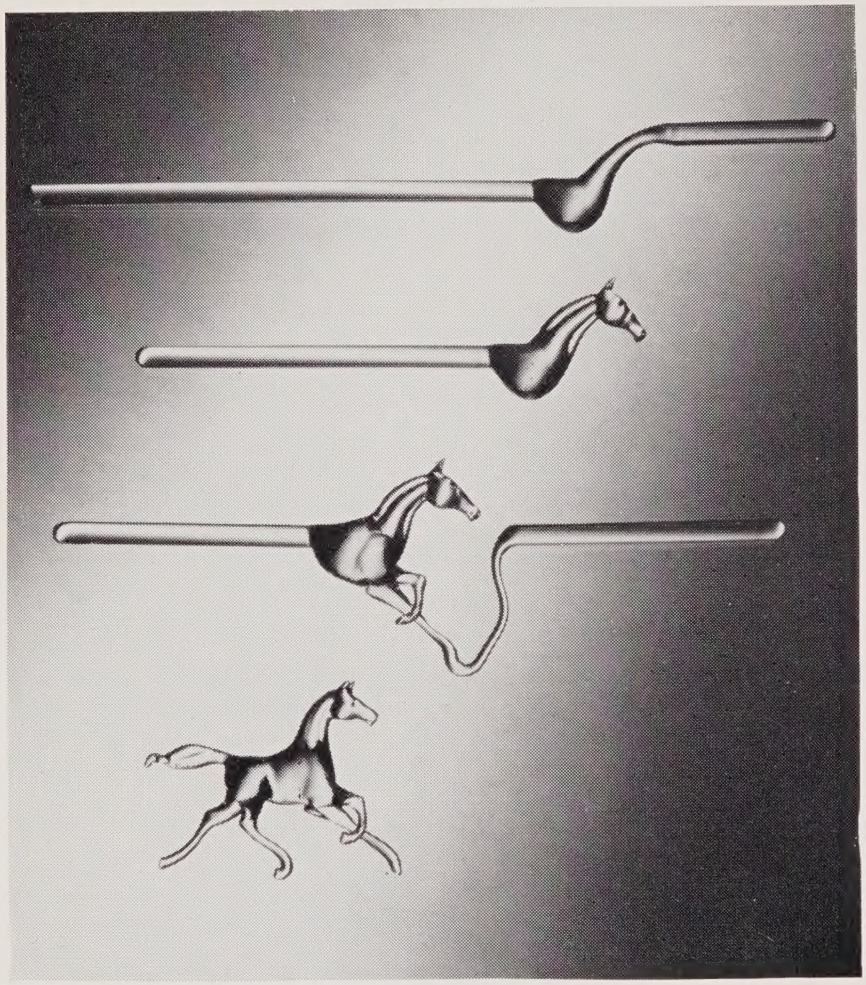
Open end of jacket is heated, drawn out and sealed to pre-formed conical joint.

Pieces of tubing and rod are reheated over air/gas or air/gas/oxygen flames and reshaped by means of tools and lathes. The different components, including end pieces ground to standard sizes to ensure exact fit, are welded together. Complicated or simple apparatus is formed by fitting the finished sections into each other.



The completed part can be assembled with other interchangeable parts.

Lamp Working



Glass animals can be made by this method.

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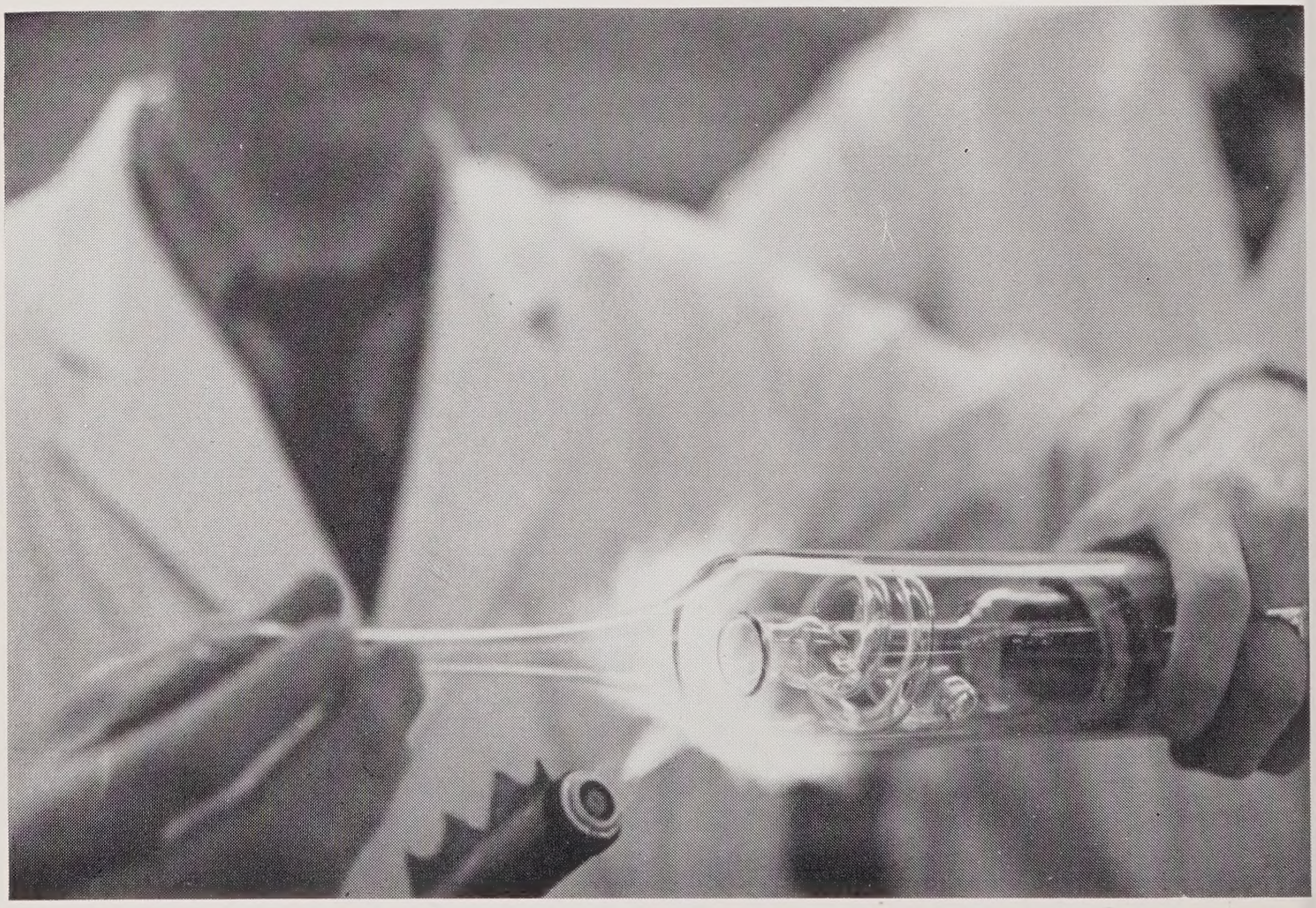
Manipulating tubing to form a distillation tube.



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